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PENNSYLVANIA GLACIATION FIRST PHASE

MATERIALS FOR A DISCUSSION OF THE ATTENUATED BORDER OF THE MORAINE DESCRIBED IN VOLUME Z OF THE SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA

BY

EDWARD HIGGINSON WILLIAMS, Jr.

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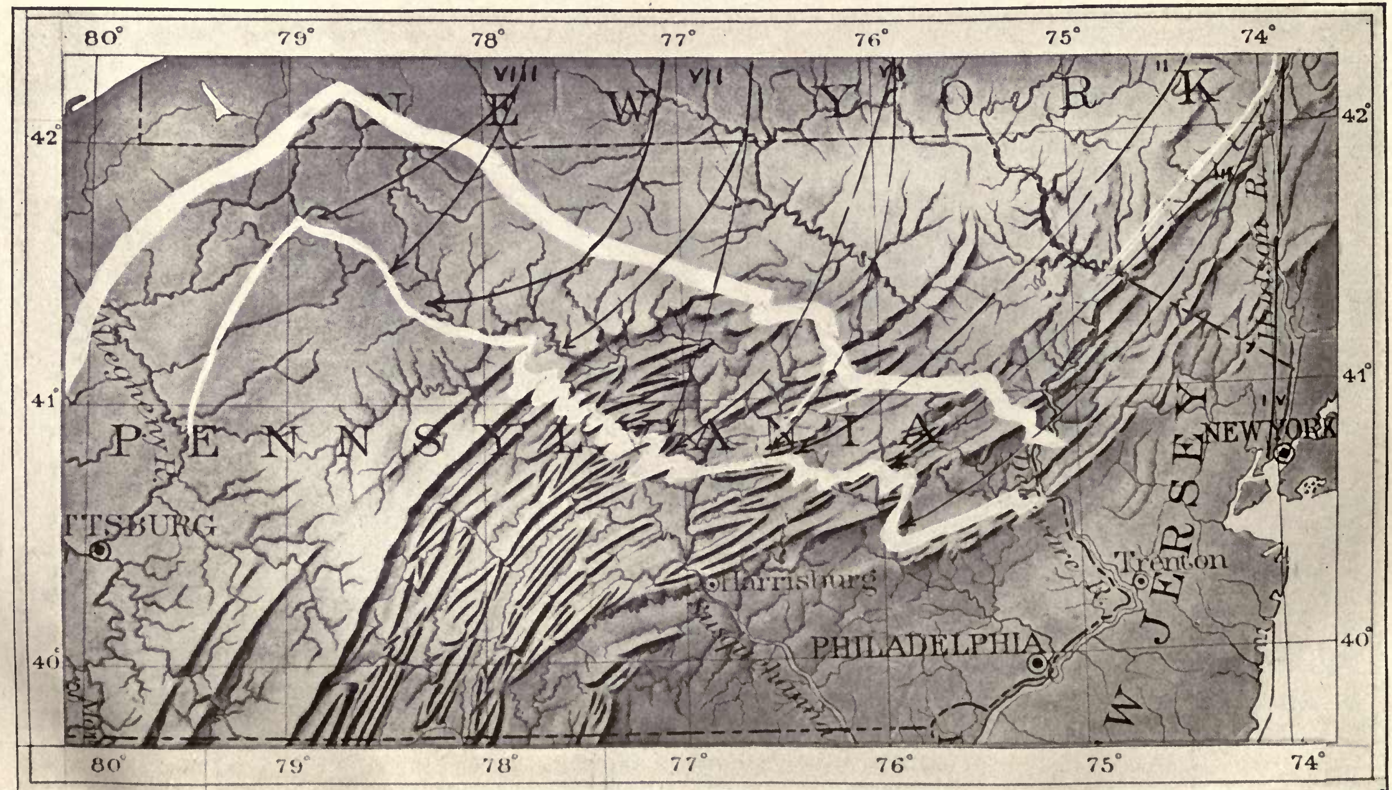
LECTURER ON MINING AND GEOLOGY

IN LEHIGH UNIVERSITY

WOODSTOCK, VERMONT

1917

PENNSYLVANIA GLACIATION
FIRST PHASE



Relief Map of Pennsylvania showing the great moraine and the boundary of the Attenuated Border.

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PREFACE

A revision of previous work on the Attenuated Border became imperative when it was found that "drift" could consist of pieces neither rolled, glaciated nor moved from an outcrop, but merely disturbed by the advance of the First Phase of the glacier, which brought nothing foreign.

The glacial striæ are associated with the regional troughs along which this Phase moved towards and upon Pennsylvania in the form of low and weak lobes, and over which the greatest motion obtained during the Mature Phase. The outcrops crossed furnished a check-list of probable rocks in the drift. The drainage lines marked where each lobe lost some of its basal burden. The origin of the stony gravel was solved. These criteria agreed with President T. C. Chamberlin's assumption of a Labrador glacier moving to Illinois.

Native copper and crystalline rocks are found only in the extreme eastern and western parts of Pennsylvania in the drift of this Phase. In both localities floating ice seems to have played an important part. With no intention of claiming a Lake Superior origin for the Connecticut and Eastern Pennsylvania copper, the latter can not come from the Trias entirely, as it is found in Monroe County, north of Kittatinny Mountain. Western Pennsylvania copper certainly has a Keewatin origin, and the specimen was berg-carried.

As the surface of Mohawk Valley is everywhere below 500 feet above ocean level, and as Central New York was flooded far above that elevation, ice-cakes could have floated into the Hudson without insisting upon an extension of Professor Spencer's Erigan trough thither, and the assumption of his rock-floor levels north of Potter County, Penna., has no bearing on a Hudson outlet.

The mining engineer will find something of interest in the "mucking" of 60 feet of slate outcrop, by which the merchantable product is quarried beneath loose drift. The mining of anthracite with the highest of carbon ratios from beneath glacial gravel is interesting as showing that an exposure of many thousand years has no appreciable effect on this coal.

Thanks are due to the members of the classes in geology at Lehigh University for aid during the reconnaissances of the summer vacations, and especially for accurate lines of level; to my former assistants, Drs. Joseph Barrell and Herman E. Kiefer who traversed the entire Border between the Delaware and Allegheny rivers; to the Director of the United States Geological Survey for permission to use the relief map (frontispiece) as a basis for tracing the great moraine and the boundary of the Border, and to my friends, Professors G. Frederick Wright and Benjamin L. Miller for

valued assistance and criticism. The following papers are frequently referred to.*

EDWARD H. WILLIAMS, JR.

WOODSTOCK, VERMONT,
February, 1, 1917.

*(*A*) Leverett, F., Monograph XLI, U. S. Geol. Surv., 1902.

(*B*) Williams, E. H. Jr., Extramorainic Drift between the Delaware and the Schuylkill, Bull. Geol. Soc. Amer., vol. v, pp. 281–296, 1893.

(*C*) *Ibid.* The Age of the Extra-Moraine Fringe in Eastern Pennsylvania, Amer. Jour. Sci., vol. xlvii, pp. 32–36, Jan., 1894.

(*D*) *Ibid.* Notes on the Southern Ice Limit in Eastern Pennsylvania, *ibid.*, vol. xlix, pp. 174–185, March, 1895.

(*E*) *Ibid.* Notes on Kansan Drift in Pennsylvania, Proc. Amer. Philos. Soc., vol. xxxvii, No. 157, April, 1898.

(*F*) *Ibid.* Kansan Glaciation and its Effects on the River Systems of Northern Pennsylvania, Proc. & Collect. Wyoming (Pa.) Histor-Geol. Soc., vol. vii, Jan., 1902.

(*G*) Wright, G. Frederick, The Ice Age in North America, 5th ed., 1911.

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INTRODUCTION

CHAPTER I

TOPOGRAPHY

Southeast of Alleghany Mountain Pennsylvania topography depends on geological outcrop. The ridges are Oneida, Pocono and Pottsville; the valleys, trenched into Trenton, Lower Helderberg, Salina and Mauch Chunk. The monotony of the level ridge crests is due to the Harrisburg peneplain. The Susquehanna, Lehigh and Schuylkill disregard the law that the drainage should follow the soft outcrops, and break through many ridges at low-angled gaps. While the river troughs were mainly trenched preglacially, their finish in some cases is due to glacial torrents. Geological outcrop has little effect on topography northwest of Alleghany Mountain. While the preglacial topography north of the Pennsylvania plateau has been modified, and in places submerged beneath a thick drift-sheet, that south of the same approximates closely to preglacial contours.

The dependence of topography on outcrop is illustrated by the extension of the Great Valley of Pennsylvania through New Jersey, the Hudson Valley, and Lake Champlain in Cambro-Ordovician measures. Its rock floor is at times far below ocean level, and rises above it 150 feet at Smith's Basin, N. Y.; 514 feet at the Wallkill-Rondout saddle, and 490 feet at Topton, Pa., and thus furnishes the only low level approach from Canada to Maryland. By this there was an escape for both ice and flood when the Hudson lobe was pocketed at Storm King Mountain. The average breadth of Hudson Valley between the 500-foot contours is 16 miles; between the 1000-foot, 32 miles. South of Kingston the eastern valley wall approaches the river till at Storm King Mountain it rises 1200 feet above it. Marlboro Mountain, opposite, forms an equally high wall. The southern outlet of the pocket is but 3/5 of a mile broad at the 500-foot contour, and 2 miles at 1000 feet. From the valley trend between Hudson and Kingston there is the same angular turn to enter the pocket as to pass southwestward along the above low valley to Pennsylvania. This valley varies from 6 to 2 miles in breadth between the 500-foot contours, and 16 miles, at 1000 feet. The closing of the Storm King pocket sent both ice and flood towards Pennsylvania.

In what follows regarding the supposed Erigan system of Professor Spencer, only the accepted depths of rock floor beneath Lake Ontario will be used. The flow of Keewatin ice-cakes eastward probably occurred before the Labrador ice fell into the Central New York depression. There is today a channel through Mohawk Valley everywhere below 500 feet above ocean level, and immediately west of the Mohawk headwaters the filled condition of the region is acknowledged. It is evident that icebergs might cause clogging which would pond water sufficiently to float them, when the clogging broke, into Hudson River. In this sense the Erigan drainage into the Hudson is accepted, without claiming a definite channel of low level.

It is evident that the St. Lawrence Valley is continued westward by a deeper rock trough. There is a drop of 700 feet from the rock shelf of the lake to the trough bottom. The Niagara promontory rises 900 feet above this valley which winds about it *via* Ancaster, Canada. The present Wabash watershed is 800 feet above ocean level. The rock floor of the supposed Erigan trough has a fall, west of the supposed Genesee confluence beneath Lake Ontario, of 1.37 feet per mile. If there were a continuation of this through Mohawk Valley to the Hudson rock floor at Storm King Mountain, the fall would be 1.42 feet per mile. This is merely interesting, in view of the evident distribution of native copper nuggets (90 to 200 lbs.) in drift near New Haven, and in small nuggets and shots in Eastern Pennsylvania drift.

The northern border of St. Lawrence Valley slopes gently to the river; the southern border rises sharply therefrom. The trough is 100 miles south of the median line between its high borders. The southern border passes along the Maine-Vermont boundary to the line of the Green Mountains. It can be considered as passing southward along them to the latitude of the Catskills, and thence westward through them and along the Pennsylvania plateau crest. The Adirondack uplift is considered as in St. Lawrence Valley and surrounded by three troughs whose filled surfaces are everywhere below 500 feet above ocean level. The uplift averages 3500 feet, many peaks rising above 4000, and Mount Marcy to 5344. At 500 feet above ocean level the area of the uplift is over 18,000 square miles; at 2000 feet, 3,800 square miles. The Black River Valley and a col at 1000, over which a lobe passed, separate this uplift from an extension whose summits rise nearly to 2000 feet above ocean level.

The Maine boundary rises above 2000 feet. This continues across the northern part of New Hampshire and varies on either side of this elevation across Vermont till the Green Mountain extension is reached, where it rises above 3000 feet, and sinks thence to 500 on the eastern rim of Lake Champlain, whose valley is 35 miles broad at this elevation, and 55 miles at 1000 feet. Its water level is slightly below 100 feet above ocean level. The Green Mountains continue the high border at an elevation above 2500 feet, with peaks rising to 4000. The Catskills rise to 3500-4000 feet, with foot-hills below 3000. The Pennsylvania plateau extends westward at 2000-1600-2500 to its culmination in Potter County, with extensions at 2200 through McKean and Warren counties into Cattaraugus and Chatauqua counties (N.Y.) at the same elevation; the Cattaraugus extension ending in the Salamanca promontory which drops abruptly 1170 feet to the rock floor of Allegheny River on the north and west, and to the Tuna Valley on the east. Beyond this river the plateau rises as a high wall which is continued northwestward as the Niagara promontory, above described.

The rise from the filled Mohawk trough to the crest of the Catskill foothills is 1800 feet; from the same to the Pennsylania plateau, south of the Black River saddle, 1600; from the Seneca-Cayuga trough, 1200; but only 600 thence to the Stokesdale saddle into Pine Creek. From Erigan rock floor to Potter County swamp, via Genesee Valley the rise is 3100 feet. The profile from Erigan rock floor southward in the meridian through Salamanca, N. Y. places the 250-foot (above ocean level) contour 12 miles south of the trough line and 700 feet above it; the 500-foot contour is 22 miles; the 1000-foot, 52 miles; 1500, 60 miles; 2000, 85 miles. The crests of the plateau at Salamanca rise to 2350, and thence is a fall of 1320 feet to the Allegheny rock floor. A second profile in the meridian, 25 miles west of the former, places the 500-foot contour 18 miles south of Erigan trough; 1000, 44 miles; 1500, 47 miles; 1900, 65 miles. A third profile between Niagara Falls and Warren, Pa., places the 500-foot contour 24 miles from the trough; 600 (top of Niagara Falls promontory), 40 miles; filled Lake Erie floor, 52 miles; 1000-foot contour, 72 miles; 1500, 74; approximate rock floor of buried Allegheny (900), 84; 2000-foot contour, 104; 2100 (crest of Quaker Ridge), 114; rock floor of Conewango (1100), 118 miles. These show a ridge 40 miles long parallel to the trend of the ice-sheet and 2400 feet above Erigan trough. The Upper Allegheny trough lay from 700 to 1000 feet below this ridge, and south of it the plateau rose abruptly between 1000-1200 feet.

Regional striæ show that eastern and central Pennsylvania were covered by lobes from the main trunk which passed up Erigan Valley to Illinois on a trend parallel to the Allegheny high wall and trough. It has been noted that Erigan trough was 100 miles south of the valley center. This produced such a tendency to adjustment of the mass of the ice-sheet towards the trough that it pressed strongly against the southern border, and induced lobation followed by united movement of the whole sheet over the Pennsylvania plateau, while Northwestern Pennsylvania was covered by the spreading of the southern margin of the main trunk.

Applying the components of the regional striæ to a topographical map we find that definite ice-streams separated from the main St. Lawrence trunk at three branching places. The first is Lake St. Peter, in St. Lawrence River; the second, 100 miles up stream, into Black River Valley; the third, 200 miles up stream into and across Erigan Valley at the foot of Lake Ontario, where there was a drop of over 700 feet.

From Lake St. Peter a lobe passed up St. Francis Valley, across the basin of Lake Memphremagog, over the Connecticut watershed (+2000) 125 miles distant, with passes at 1120, 1246 and 1214, and through Connecticut Valley to Long Island. This will be called the *St. Francis-Connecticut River Lobe,* or No. 1, and will not be further considered as its only influence on Pennsylvania glaciation was the reflex of its own resistance to progress.

A second lobe passed at once from Lake St. Peter into the broad mouth of Lake Champlain Valley. This narrows to 5 and 3 miles between Whitehall and Stony Point at the 500 foot contour, and to 17 at 1000 feet. It broadens at Fort Ann to 9 and 27 miles at these elevations; to 16 and 25 miles at Smith's Basin saddle (150). Thence to Kingston, N. Y., is an average of 16 and 35 miles. A branch separated from this at Smith's Basin, and two more at Kingston. This separation was not immediate, as the main body had moved on its way for centuries, if not millennia, before the splits left the region.

At Smith's Basin the main body moved down Hudson River by turning to the left; while the split continued in the Champlain trend to the Mohawk trough, where it had to rise 1000 feet to pass its southern wall, and an additional 900 feet to cross the Delaware watershed. It could then move down the Delaware Valley to the eastern boundary of Pennsylvania with a fall of 500 feet in the plateau surface and of 1000 feet to the Delaware trough. Thence there was a long and easy rise over broken country to the crest (2200-2500) of the Moosic-Pocono ridge, which was accompanied by a contraction in breadth to 42 miles at that crest; to 20 miles at the headwaters of Lehigh River; to 12 miles against Susquehanna River. Before crossing the high southern bank of Mohawk River it spread up that valley, and thus, when it moved southward it crossed also the headwaters of the most eastern of the affluents of Susquehanna River. There are passes at 1550, 1500, 1410 and 1365; the two former to the Delaware, the latter to the Susquehanna. This lobe will be called the *Champlain-Mohawk-Delaware-Pocono-Shamokin Lobe,* or No. 2. It reached the Lehigh headwaters several thousand years after No. 3 attained its farthest bounds and had passed away.

The split that passed directly down Hudson Valley was pocketed at Storm King Mountain and deflected up the Wallkill-Rondout valleys towards Delaware River and Pennsylvania, along a trough bottom always below 520, with bordering ridges always with smooth flanks parallel to the glacial trend, so that additional thickness brought only commensurate bottom drag. The accompanying glacial drainage gave a water-worn *facies* to all of its drift. This will be called the *Champlain-Hudson-Delaware-Schuylkill Lobe,* or No. 3. Its drift is the oldest in Pennsylvania, and in New Jersey is called "Jerseyan."

When the pocketed ice at Storm King Mountain was thick enough to cross the 1200-foot wall, two lobes moved therefrom. One passed to the Hudson mouth, the other to New Haven, Conn. The *Champlain-Hudson-Manhattan Lobe,* or No. 4, does not enter into this discussion. The *Champlain-Hudson-New Haven Lobe,* or No. 5, is interesting as it carried from the main Hudson trunk masses of native copper up to 90 and 200 pounds, while No. 3 carried shots of the same to Eastern Pennsylvania.

From the second branching place a lobe passed from the St. Lawrence up Black River Valley 140 miles to the broad saddle at 1000 feet, whence there was a drop of over 1700 feet to the rock floor of the Erigan-Mohawk trench and a greater rise to the Susquehanna watershed with cols at 1250, 1265 to the Unadilla, and at 1150 to the Chanango affluents. These cols, by piracy, are now several miles north of the watershed. West of the Chenango basin a 2000-foot ridge separated this lobe from No. 7, which also drained its portion of the 160 miles along Central New York into Susquehanna River. On reaching the summit of the Pennsylvania plateau this was separated from No. 2 by Moosic Mountain, whose high wall prevented the lobe from entering Lackawanna Valley. It crossed this Pocono wall at Pittston Gap, where the southern side is debased to 1000, or 1000 feet below the crest from Moosic Mountain southward. This wall rises again to 1500 at Plymouth and is in 1500-1600 to the end at Huntington Mountain, where the great moraine was pocketed. This lobe was 75 miles broad at the Pennsylvania boundary; 50 at Wilkes-Barre; 55 at Catawissa; 25 at Selins Grove; and 10 at the McClure saddle. It will be called the *St. Lawrence-Black River-Susquehanna Lobe,* or No. 6.

From the third branching place there was a fall into the Erigan trough. If this were partially drained into Hudson River the ponded water in it was below 800 feet above tide, but if the drainage were westward the level of ponding made 550 feet of depth above the rock shelf along the northern shore of Lake Ontario, and 1300 over the Erigan rock floor—both sufficient to cause calving of bergs from the glacial margin until the valley was completely clogged and the trough filled, when two lobes separated. That to the east moved into the Cayuga-Seneca lake pocket, 90 miles broad at the mouth between the 1000-foot contours, 75 miles north of Pennsylvania, but 30 broad at the bottom, 20 miles away, with a ridge as a stopper (1200) and passes, to the east (920); to the west (990)—both leading into the Susquehanna River. The Chenango pass has been noted above. This lobe moved southward across the state boundary and then opened fan-wise: the left margin continuing southward to Muncy, crossing Bald Eagle Mountain, and reaching almost, if not quite, to Penns Valley; the right, caught in the broad and low troughs of the plateau top, was turned westward so as to cross Sinnemahoning Creek to Medix at right angles to the trend of the other part. This is 35 miles broad at the state boundary; 60 at Lock Haven; 32 at Medix. It will be called the *Ontario-Finger Lake-Allegeheny Plateau Lobe*, or No. 7.

The western split moved up Genesee Valley, crossed its high western wall and the Allegheny trough at Vandalia, N. Y., reached the crest of the Pennsylvania plateau in Potter County and reached Kane and the headwaters of Kinzua Creek. This is called the *Ontario-Genesee-Sinnemahoning Lobe*, or No. 8.

An examination of the outcrops crossed by each lobe enables us to predict the possible contents of the drift of each. The location of torrents to be crossed permits the possibility of the loss of basal burden. Each lobe thus has a peculiar drift-sheet, approximating to the regional outcrop where it rests.

CHAPTER II

THE FIRST PHASE

The initial movement of the first glacier was of necessity burdenless and over an aged, soft and deep surficial mantle. There was no frontal moraine during its progress, as this depends on the sum of *continuity in action, supply of material* and *permanent deposition.* The *bulk* of a moraine depends more on the last than on the power of the ice-sheet or its percentage of burden. The moraine of Lewis & Wright in Cherry Valley, the drift sheets that have obliterated preglacial topography in Western New York, are vast because they were dropped against ponded water in such bulks as to prevent return of preglacial lines of drainage. There were vast amounts of burden in the ice-sheet as it lay across Lycoming Creek, as shown by the Juniata gravels; but there is no sign of a moraine at the crossing or for some distance on either side. The ponded water in Erigan Valley has been noted. This was pushed over the Pennsylvania plateau in such volumes that the river trenches were unable to discharge it, and it swept the surface along lines of accumulation.

Again, the initial glacial mass was of the highest fluidity, possessed a low front (probably 300 feet 1 mile from the face), a tendency to ready lobation, free passage of heat rays and thus great bottom depletion. This last produces frequently a movement of vertical ridge outcrops indifferently to the valleys on either side, whether the glacial movement is with or across their strike. Its effects are seen also in the "Rock Cities," which can hereafter be taken as evidences of an ice-sheet. The ridge-crests of Northwestern Pennsylvania are residues of highly jointed horizontal strata. The stagnant ice molds itself over these, opens the joints, envelopes the separated masses and moves them radially from the crest to various distances, leaving them with strata still horizontal, and joint-planes vertical. A third effect of bottom depletion is the uncovering of crests and exposure of drift-caps to erosion during the settlement of ponded water. The heavy residues at high levels attest the former extension to those levels of drift-sheets now buried beneath washes in the regional troughs.

Fluidity also imposed a rolling motion to the progress of the ice-sheet, with a maximum retardation of basal burden. Mr. Upham[1] has considered 100 feet per year as a maximum rate of progress for basal ice, and one-half to one-third of the same as the probable rate. With a main trunk 400 miles broad and so slow a frontal progress it is evident that there would be little or no motion parallel to the central trend along a lateral margin spread along a series of ridges and troughs normal to that trend, especially if that margin averaged 2500 feet above the trough bottom. The boundary of such a margin would show no lobes, but crenatures varying in acuteness and extent with the breadth of the troughs and the rise of their bottoms.

The rise along the center of each lobe varies with fluidity, nourishment and resistance to progress. Lateral spreading is conditioned upon an excess of nourishment over depletion, and is a function of the above three; but in any case it is always slower and more intermittent than frontal progress. In the case of Northwestern Pennsylvania it was vastly more easy to move from the Niagara Falls region 325 miles along a low trough with a rise of 200 feet, than to move at right angles to the central motion 100 miles with a rise of 2000 feet.

In an attempt to arrive at comparative slopes of the various lobes there was used the rule reported by Mr. Lesley[2] as original with Professor Louis Agassiz, "*That no glacier can cross a ridge unless its thickness at the summit of the ridge is at least one-half the height of the ridge.*" Measurements were taken along the line of motion of Lobe No. 3 from the Center Valley front to Port Jervis, N. Y., and thence through Mount Marcy, the highest of Adirondack Mountains, to Lake St. Peter in St. Lawrence River. The profile of the line was compiled from the state and government quadrangles. Applying the above rule it was found that to cross the average elevation of the Adirondacks, Kittatinny and South mountains, the surface of the ice-sheet would rise 365 feet above South

[1] Upham, Warren: Fields of Outflow of the North American Ice-sheet, XII Internat. Geol. Cong., Toronto, 1913.

[2] Lesley, J. P.: Letter of transmission, vol. z, p. 14, 2d., Geol. Surv. Pa.

Mountain; 585 feet above Kittatinny Mountain, 1850 feet above the Adirondack average, and 8000 feet above Lake St. Peter. The surface slopes are:

Center Valley to South Mountain, 126 feet per mile (1° 23′ 32+″); South Mountain to Kittatinny Mountain, 43.5 feet per mile (0° 22′ 29+″); Kittatinny Mountain through Mount Marcy, 15.5 feet per mile (0° 11′ 06+″).

These slopes are like those of modern continental ice-sheets. Mount Marcy and Mount Washington of the White Mountains would be buried 300 feet below this surface, while Slide Mountain and the four next in height of the Catskills would emerge from 100 to 825 feet above it.

In the following calculations the results are interesting rather than conclusive. At best they are comparative, and as such may afford a means of arriving at an estimate of the relative times of arrival of the various lobes at their destination. From the above slopes it appears that the surface of the theoretical ice-sheet is about 800 feet above the elevation of the frontal base at a point 11 miles in the rear of the latter. This can be separated into a rise of 300 feet for the first mile and of 50 feet per mile for the following ten. Assuming these figures for the fronts of the five lobes that invaded Pennsylvania and selecting stations on those fronts, the relative slopes of each between Lake St. Peter and points 11 miles back from each front can be found, measuring the distances along the paths followed by each lobe. These distances can be quite accurately measured along Lobes 2, 3 and 6, as their boundaries are established within a mile. In Nos. 7 and 8 it is only possible to say that the ice-sheet may have gone farther than the points selected. These are:

No. 2, the inside of the Pocono rim where Line and Little mountains enclose the Mauch Chunk Valley of Zerbey Run, elevation above ocean level, 800 feet.

No. 3, Hamburg, Berks County, against Schuylkill River, elevation, 550.

No. 6, McClure, on the border of Snyder and Juniata counties, elevation 640.

No. 7, Medix, in the southeastern corner of Cameron County, in a narrow river trough about 1150 with the plateau average above it 1600.

No. 8, Kane, on the top of the McKean County plateau, 2000, with average of region 2100.

No. 2. Little Mountain, 448 miles, slope 14.64 feet per mile.
No. 3. Hamburg, 443 miles, slope 15.41.
No. 6. McClure, 465 miles, slope 14.44.
No. 7. Medix, 461 miles, slope 12.44.
No. 8. Kane, 445 miles, slope 11.74.

The distances along the different glacial trends agree very well, although the profiles show great variations in elevations overcome. This raised the question whether this boundary line of the Attenuated Border could not be taken to represent the curve of work done by this phase, and the great moraine to represent that done by its phase. To institute a comparison, lines were drawn from the above stations along the lines of glacial flow to the above moraine, and other stations thus found thereon, with their elevation above ocean level. The distances between these stations were measured, the above average slopes calculated back for those distances, and the elevations of the surfaces of the above lobes found at points 11 miles back from the second series of stations. The stations, distances from boundary to moraine, their elevations above ocean level, and the elevations of the glacial surface of each lobe are as follows:

No. 2. Little Mountain (800) to Sandy Run (1000), 61 miles, surface 2493.
No. 3. Hamburg (550) to Nazareth Junc. (600), 48 miles, surface 2089.
No. 6. McClure (640) to Beachhaven average (900), 66 miles, surface 2398.
No. 7. Medix (1600) to Lloyd (1600), 58 miles, surface 3221.
No. 8. Kane (2100) to Rose Lake (2055), 50 miles, surface 3487.

Subtracting the elevations of the second series of stations from the elevations of the lobes behind them we find the rise in 11 miles for each to be: No. 2, 1493 feet; No. 3, 1489; No. 6, 1493; No. 7, 1621; No. 8, 1432 feet; average, 1520. This last figure agrees well with modern types of continental ice-sheets in rising 500 feet per mile for the first mile, and 100 per mile for the next 10 miles. When this is considered with the parallelism between the above boundary and the great moraine it seems plausible to suggest that they are representatives of the first and mature phases of the same ice-sheet, especially as their drift-sheets are identical, as far as clastics are concerned, and the crystallines of the moraine are absent from the outer border because of the retardation of the basal ice.

Taking up the second part of the calculation the question will be asked if it be possible to arrive at the relative times of arrival of these lobes at their boundary, using Professor Agassiz's rule for thickness, and Mr. Upham's for speed. The former is definite, the latter relative, and the periods will be measured in years of 100 feet progress. As an example, Lobes 2 and 3 separated theoretically at Smith's Basin, N. Y., though the barrier between them was not visible on the surface till the rise along Hudson River to Catskill Mountains was reached. There was no obstacle before No. 3 until within 25 miles of Delaware River, where the Wallkill-Rondout watershed to the latter rose to 514 with easy slope from Hudson River. No. 2, on the contrary, must rise 1000 feet within a mile or two to cross the southern bank of Mohawk River, and 1900 feet to cross the Hudson-Delaware watershed. On reaching the Delaware River boundary of Pennsylvania there was a farther rise of 1300 feet to the Moosic-Pocono plateau.

With the above rule for thickness the ice-sheet must have stood 900 feet above the Delaware watershed and have had a surface elevation of 2700 feet above ocean level at a point 84 miles south of Smith's Basin. This would indicate a corresponding elevation of No. 3, 84 miles from the same; but as this would be in the Hudson trough, it would indicate a thickness of 2700 feet for that lobe. With its average slope of 15.41 feet per mile, its front should be many miles to the south. The average elevation of the Wallkill-Rondout trough is 300 between the Hudson and its watershed, and this average continues into Pennsylvania. Adding this elevation to the assumed 800 feet of rise 11 miles back from the front of the First Phase lobe, we can find the distance from the point 84 miles south of Smith's Basin to where the glacial surface would be 1100 feet above ocean level with a slope of 15.41 feet per mile, or 104 miles, which would bring the front 11 miles farther, or across Delaware River and half way between Belvidere and Martin's Creek. From the watershed to the Delaware River boundary of Pennsylvania No. 2 would move down a slope for 60 miles. Supposing both lobes moved with equal speed, which is favoring No. 2, the front of No. 3 would have advanced 60 miles farther, or 63 miles from Belvidere, and 8 miles beyond its farthest extension. This would indicate that No. 3 ended its advance before No. 2 touched Pennsylvania. The distance from Smith's Basin to Hamburg is 240 miles along the Cambro-Ordovician trough. At 100 feet per annum No. 3 would cover the distance in 12,672 years, and No. 2 would require about 13,000 years to reach the eastern Pennsylvania boundary. It would remain near there till its front thickened from 300 feet frontal elevation to an elevation above ocean level sufficient to send a thickness of (one-half of 1300 above) 650 feet over the Moosic-Pocono plateau, 32 miles distant from the river crossing. With the slope of 14.64 feet per mile this would indicate an increase of 2500 feet above the original 300, and an uninterrupted progress along a plain of 180 miles, at 14.64 feet per mile. Its rest along the Delaware River till it moved across the Moosic-Pocono ridge was about 9500 years, and its progress about 16 feet per year. It would reach the headwaters of Lehigh River long after No. 3 had reached its bounds and had been more or less completely removed. This accords with the consensus of opinion that the drift of No. 3, called "Jerseyan" in New Jersey, is the oldest in the region. It also accords with the conditions in the Lehigh Valley, where the earliest efforts of No. 2 over the headwaters of Lehigh River come after the last of the deposits from No. 3 have been laid, as will be described later. Owing to lack of accurate data along the profiles of the other lobes no further comparisons will be made. In other ways we are able to find overlaps and coalescences of neighboring borders without decision as to relative times of arrival. It is probable that the youngest is the most westerly, and that the spreading of the margin of the main trunk over Northwestern Pennsylvania was near the ending of the advance.

CHAPTER III

THE FLUVIAL FORCES

From the dimensions of trenched cols we know that streams of great power were at work, but from the sizes and shapes of the assorted pieces in the deposits we know that their velocities were considerable only when confined to the trenches. Otherwise they swept slowly across broad areas and left abundant deposits where ponding or slackened currents obtained. The presence in the drift of large rock-masses, or cobbles and boulders above the average indicates ice-carriage in the mass or by bergs and cakes.

The average small sizes of the assorted pieces in the deposits makes the current velocities that carried or dropped them pertinent to this inquiry. Fine clay is worked by a stream of 3 inches per second; fine sand, 6; coarse sand, 8; fine gravel, 12; 1-inch gravel (round, 24; angular, 36). If 1-inch round and angular mixtures are fed into a 24-inch stream, at the end of the operation the bottom would show angular only. This is why in slabby regions, in spite of abundant glacial gravel fed to streams, the bottoms are purely slabby. Where Kettle Creek meets Lake Lesley we find round gravel—otherwise its bottom is slabby, as are the other Sinnemahoning affluents that drain the glacier. Oil Creek bottom above the great moraine is also slabby.

The water-worn character of the drift in general shows that the First Phase was a fluvial one, and especially in Northwestern Pennsylvania where the southern margin of the main trunk spread upwards to the Pennsylvania plateau. Before the level of ponded water reached the col at the head of the submerged valley the combined floods of regional and glacial discharge escaped along the marginal canyon trenched between the glacial margin and the regional slope, and as the ice-sheet moved upwards this canyon and its floods were pushed higher and higher along the slopes. The area of the canyon would thus vary greatly as it crossed flooded valleys or was trenched through the intervening ridge-crests, and where occasion offered there would be deposition of coarser sorts, which now are called "high-level channels," "high beaches," as they cling to the sides of valleys above present water level.

The rivers on the southern sides of the cols were trenched by the floods forced over the cols, and thus a large part of the trenching they show today was performed before the actual advent of the ice to their basins, though the agents may have been more or less glacial. The Susquehanna, Schuylkill and Lehigh are good examples, and all three flow in places over glacial fillings 50 feet deep.

There is a difference in the efficiency of the glacial dam whether the ice-sheet moves up or across a valley. In the latter case there is a leakage owing to the constant adjustment of the ice along its periphery to the inequalities of the surface over which it passes, and this leakage, with proper head and volume may become sufficiently erosive to remove the basal ice, especially as it would require, according to Mr. Upham (*op. cit.*) from 1 to 3 years for that layer to cross a stream 100 feet broad. The only efficient dam is where the margin of an ice-sheet spreads upwards so as to pond all the drainage of a region and to discharge it along a marginal canyon. The flood in this latter erodes the regional slope and especially the ridges across which the canyon is located. The local material thus removed is dropped with the glacial *débris* against the ice-margin where it crosses the submerged valley, and thus stops all leakage by forming a deep deposit over which the ice moves upwards. The result is to fill, and even obliterate old channels and valleys, by hundreds of feet of drift, as in Western New York, which remain undisturbed because the trenching of Big Bend and other cols from 450 to 1000 feet furnished a permanent escape for the regional drainage southward. Drive-pipe records attest to the great depth of filling in the above valleys.

The carriage of drift to high levels by ice-cakes borne on the crest of long and high waves, incident to the bursting of ephemeral ice-dams formed by icebergs and cakes in the "narrows" of streams, has been described for Juniata River by the writer (*cf.* preface note D, pp. 182–183). The three great areas of ponded water in the state have been mentioned: Lake Packer (preface note B, pl. ix); Lake Lesley (*ibid.*, D, p. 184); and Lake Allegheny (*ibid.*, F). The first two names remain, with due regards to Professor Wright (*ibid.*, G, p. 153) for suggesting another name for the first. The last name has been preëmpted for other things, and a further study of the region makes it impossible to comprise the various areas of ponded water—now connected, now separate—under one name. They can be described under three aggregates. The most northerly is connected with the old Upper Allegheny Basin, and for a long time it included the second, which covered the Warren-Clarendon area. The third covered the old Middle Allegheny Basin. For the first the name *Lake Wright* is suggested, as Professor G. Frederick Wright was the first to claim a continuity of the Indian Hollow (East Warren) deposits. In addition he gave to the writer 25 years ago, the impetus that induced him to examine the Attenuated Border. The second much smaller body is called the *Conewango Slack Water*. For the third the name *Lake Leverett* is suggested, as the monograph (preface note, A) of Mr. F. Leverett has been followed by the writer in the arrangement of the various preglacial Allegheny drainages, and has left little undone in marking the boundary of the Attenuated Border there. These will be described later.

The action of a reversed stream discharging over the col at the valley head is interesting. The current starts from the old valley mouth, or wherever the ice-margin crosses, and moves to the upper wedge-end, acquiring velocity from two causes: the narrowing cross-section and the discharge of affluents. The old projections, bars, deltas, have been sculptured to favor movement down stream, and the reversed current moves against and is deflected by them. The head-on discharge of each affluent is against a gradually swifter flood. There is no such quiet flow as in a torrent of equal head moving down stream; there is a struggle between warring forces which must tear away all projections and fill all holes where slackness prevails. Only when this is done behind shoulders of hills, or on the inside of bends, does anything like smoothness of flow obtain. Today we find these fillings of holes far above present water level, and we must not mistake them for complete valley fillings. The great classical gravel deposits of East Warren, Brandon and Kennerdell are foreset deposits in holes of reversed currents.

The col at the head of a reversed current is trenched by material taken immediately from its vicinity. The current on starting from the ice-sheet is at its slowest speed, and drops everything of bulk against that sheet. As it acquires velocity it picks up burden of the lighter and smaller sorts, and this becomes heavier with increase in velocity till, at the wedge-end of the valley it tears away the entrance to the col trench and cuts down the sides and floor with this coarse material, which is immediately dropped as soon as the trench is past and the current slackens in the broader valley beyond. When the trench is sunk to the level of the old valley mouth there is a channeling through the old valley floor. This depth of trenching seldom happens and there is generally a portion of the old filling remaining as a floor for the stream. Infrequently, and where a plunging scour obtained, the old rock floor at the valley head for a considerable distance from the col is cleared from its drift filling. After this flow subsides an area of shallow ponding remains that is filled with late foreset beds.

CHAPTER IV

DRIFT OF THE FIRST PHASE

This covers in Pennsylvania a strip 300 miles long and (measured in the meridian) 43 miles broad east of McKean County, but (measured on N. 45° W.) less than one-half that distance west of the same. The drift is uniform only in its *fluvial* appearance in and near lines of drainage, and its *angularity* and *local* character beyond their influence. The change in criteria is shown by considering, "*What is drift?*" and "*When did it age?*"

What is Drift?

The forces that induced glaciation were not localized and confined to the Labrador origin, but formed snow caps, if not local glaciers, on neighboring crests; whose ablation caused abnormal washing of ridge slopes, erosion of troughs, burdening of floods with material from the old surficial mantle that was rolled proportionally with stream power and distance carried, and deposition of the burden to form the oxidized and incompletely rolled formations that will be called below *Orogenic.* This is not true drift, though connected with glaciation.

True drift approximates to the local outcrops because of:

First.—The retardation of basal burden.

Second.—The very frequent movement of the ice-sheet along the valleys, and thus along the strikes of the measures.

Third.—The more or less complete removal of the basal burden, with the basal ice, during the crossing of a torrential stream (*cf.* p. 10).

Fourth.—The massing of basal ice against a steep rise, the shear developed, and the passage of the top clear ice to and over the crest (preface note, D, p. 182).

Fifth.—The washing of basal ice through crevasses, and the dropping of the burden where crevasses always form—on the far side of every sharp angle in the surface. Susquehanna and Oil Creek gravels will be noted below.

By the first, the frontal ice of the First Phase was clean when it reached its farthest boundary. During the first year the moraine accumulations were from the 30 to 100 feet next it. Unless the outcrop of a different formation came to the surface within a mile the accumulations of from 50 to 100 years would be like those of the front. Thus, at Bethlehem for 1200 years nothing but Cambro-Ordovician limestone would be brought by the ice-sheet. The materials of a moraine would thus resemble the overturned soil of a thick mantle, such as exists in Saucon Valley south of the rock trains between Friedensville and Bingen.

This is true drift even if nothing foreign is found. In the countless instances where the surficial mantle seemed to be untouched and of ordinary thickness close observation might find one or more erratics in a mile of cutting, or a square mile of area. Mr. Barrell styled the search for foreigners, "Hunting needles in haystacks," as one erratic was frequently the sole find after days of search. The "Needles" are usually rolled pieces among angulars, red strays on white outcrops, and *vice versa,* crystallines amid clastics or coal, and other marked rocks carried above their outcrops. The bulk of the formation is as surely drift without as with these foreigners. As examples, Figure 42 shows rocks from bergs dropping in a clay lenticule (East Warren). Figure 43 is a nugget of native copper therefrom. Figure 8, a Lower Helderberg cobble in gneiss *débris.* Figure 9, some trap cobbles (right foreground) in the same. The two latter from South Bethlehem.

When did the Drift Age?

After 25 years of study it seems that the aged appearance is inherent and not acquired. Figures 1 (Saucon Valley), 2 (Lehigh Valley), 3 (Upper Juniata Valley) show the contrast between the deep red of the surficial mantle and the color of the fresh and polished cobbles. The time elapsed since drift deposition is measured by the freshest part.

Rustiness and decomposition are more rapid over the soft porous Mississippian-Pennsylvanian areas of Western Pennsylvania than over the denser ones of the Anthracite Basins, and vastly more rapid than over those with outcrops below the Mauch Chunk—excepting rocks

FIG. 1.—Brownish-red silt including quartzite cobbles, Bingen, Northampton Co.

cemented by calcite—because of the presence of pyrite in the coal measures. This, when moistened, becomes efflorescent and soluble, and when exposed to the sun and air breaks into limonite and sulphuric acid. The former stains, the latter decays whatever they touch. Such decay is especially rapid in the black bisilicates of crystalline rocks. Drift-sheets near such solutions are suspicious when stained or decayed. Where an overwash drift-sheet is underlaid by a limonite hardpan we can be certain that the latter was not only leached from the preglacial rustiness of the gravel, but was laid and hardened in its present position before the water in which the deposit was dropped had been drained away. The rustiness of the Pottsville conglomerate pebbles is found in the drift sheet and in the solid rock along a quarry face, and seems to have been inherent to the pebbles before solidification.

Fig. 2.—Cutting through bar, *West Bethlehem gravels*, Northampton Heights.

Fig. 3.—Outwash of Lake Lesley, Dix col, Blair Co.

The decay in a rock floor may also have been preglacial. In the fall of 1913 Dr. Miller of Lehigh University showed the writer the preglacially decayed limestone floor of the East Allentown gravel workings. The boulders (dropped from icebergs) fell through the 200 feet of water and "splashed" into the soft surface so as to raise a rim about them of an inch in height. Sporadic patches of denser rock came to the surface. At the time of deposition a man's footprints would have been depressed in the soft mud.

Deforestation reduced the ferric salts in the surficial silts from red, yellow and brown to blue, by intermingling vegetable matter. Leaching extracted the color and left whitish, mottled and streaked beds. Thus the blued clay is of the same age of deposition as the red orogenic clays of the same region which are found, now above, now beneath the blue. Color here is no criterion of age.

The extent of a possible scour in a region as a criterion of age must be accepted only when actual "fag-ends" of complete valley fillings remain. Deposits found where subsequent scour would not operate must be considered with the query whether the present direction of the stream which is supposed to have removed the bulk of the deposit is that of the stream by which the deposit was made, as depositions in deep water through which a current passed could have been dropped originally where scour did not operate while those portions of the valley where it was active would be swept clean. One sure proof of the latter condition is the shaping of the deposit to its present state before the sinking of the ponded water, the thinning out of strata as they came near the line of scour, and the capping by clay, sand or silt under conditions which show that it is not a slope-wash. For example, the bars between Warren and Foxburg are not remnants, as they fulfil all the conditions of those dropped where scour did not operate, as do those in the Susquehanna and Lehigh regions. There has thus been no erosion of either rock floor or of complete valley fillings in any of the main valleys of the state. They may exist here and there in some of the small side runs; but the erosion from the latter took place as the level of ponded water fell, because the main channel was open and the sands, becoming quick, ran out, as they did from beneath the gravel at Stoneham.

Lastly, the mining of slate and coal from beneath porous drift should make us adopt new criteria regarding rock decay, and assume that the fresh and undecayed rocks in drift of aged appearance indicate that the aged portion is to be assigned to the preglacial surficial mantle unless exposed to solutions from pyrite. But, as these fresher rocks are erratics and "needles," it is safe to conclude that, unless we have disposed of the preglacial surficial mantle elsewhere, the aged and decayed drift deposits we encounter along the Attenuated Border, and even in such mature deposits as are found in Vermont, must be assigned to that mantle, as it has been shown along that border that there has not been sufficient time since the First Phase for rocks to reach the state of decay of these old appearing drifts by ordinary agencies.

The length of the foregoing introduction is necessary to an understanding of the standpoint of the writer in the following description of the deposits of the Attenuated Border, and the controversial statements were necessary. It remains to consider the drift-sheets of the various lobes, the conditions of deposition, the outcrops crossed, the possible composition. The presence of very aged and very fresh pieces of an extreme foreigner in the same drift can be accounted for by glacial and berg carriage. While the former might indicate millennia of transit, the latter would be accomplished in as many hours, and would be delivered either fresh or as decayed as the piece of red granite found at 1500 on the hill south of Franklin, with angular quarry face, but pulverulent.

In the following scheme no attempt is made to form a stratigraphic column to include all the lobes. The only exception is where the Packer Clay, the first of the deposits of No. 2, is found capping the last of those from No. 3. The rocks of the drift-sheets of the lobes are so different from one another, and of each sheet so variant in different parts of its area, that it seemed well to name each of them as it is found in Pennsylvania.

SCHEME SUGGESTED FOR PENNSYLVANIA DRIFT-SHEETS

PREGLACIAL

Orogenic.—For definition see p. 14. Always approximates closely to the local outcrop.

GLACIAL

DRIFT OF THE FIRST PHASE

Lobe No. 3.—Great Valley Drift

Synchronous with "Jerseyan" in New Jersey, and a continuation of it. The expected clastics come from the lowest New York outcrops up to the Pocono. Crystallines from Canada, the Adirondacks and Green Mountains. Native copper also. The earliest drift in Pennsylvania. Crystallines found only near Delaware River and the South Mountain (gneiss) uplift.

Lobe No. 2.—Broad Mountain Drift

Expected crystallines as above. Clastics as above and including the coal measures. Foreign rocks very rare. Subsequent in time to No. 3.

Lobe No. 6.—Susquehanna Drift

Crystallines and clastics to be expected, as in No. 2. No crystallines found. Lewistown limestone and Salina shale abundant in main valley. Coalesced with No. 2 and No. 7. Rolled gravel abundant south of Susquehanna River.

Lobe No. 7.—Plateau Drift

Clastics from Ordovician to the coal measures. No crystallines found. North of Susquehanna River mainly Mississippian-Pennsylvanian; south of Bald Eagle Mountain, Ordovician to Clinton. Rolled pieces abundant south of Susquehanna River. Overwash into and through Juniata River.

Lobe No. 8.—Highland Drift

Clastics from Chemung to the coal measures. No crystallines found. Rolled pieces numerous. Outwash stratified.

Southern Lateral Margin of Main Trunk—Fluviatile Drift

The possible rock-forms run from New York and Canadian crystallines through the sedimentary measures up to the coal. Local rocks and in immediate vicinity Chemung to coal measures. Angular and local drift on ridges; rolled and crystalline drift in valleys. Iceberg action abundant. Deposition in ponded water voluminous; ridge-drift thin.

In accordance with the above scheme it is possible to eliminate the outwashes from the great moraine and to arrange the varieties of drift from No. 3, in the extreme east, and from the Lateral Margin of the Main Trunk, in the extreme west; as in both regions sections which contain all the formations noted below can be studied to the rock floor. In the extreme east alone is there a true overlap of formations from different lobes. When sections through the deposits in the center of the state afford chance for study it is probable that similar overlaps may be found. The names which follow are suggested as affording places where the various deposits can be best studied, and where they are typical.

EASTERN PENNSYLVANIA

OROGENIC BEDS—PREGLACIAL

Sporadic red, yellow and brown angular accumulations of local rocks lying against the rock floor. Noted along the flanks of South Mountain in cellar holes. Matrix of silt with inclusions of rough-surfaced and decayed pieces of gneiss. Resembles the final slope-wash that overlies the drift, but is not so sandy, and the rocks are more decayed. Overlain by drift, of similar color, but with different burden.

GLACIAL

Lobe No. 3.—Great Valley Drift

Early Great Valley Period. Land-laid Drift

The following varieties have been found, and are described without attaching significance to the order of arrangement. They indicate the local and sporadic character of the varieties which were accumulated at the same time, though in no instance have they been found to shade into one another.

A. Matrix of Damourite paste that balls like clay, greenish-gray, carrying flakes and small slabs of the mineral, usually angular and rubbed slightly on an edge; also rolled and polished pebbles of quartzite and sandstone—the latter white and with pitted egg-shell surface (see preface note B, plate 11 and context). Found only at small area along the eastern side of Rauch's Pit, West Bethlehem, against decayed and glaciated Ordovician limestone. 2 feet thick. Underlying *West Bethlehem* gravels.

B. Unassorted gravelly drift of rolled pebbles of white sandstone, quartzite, and other light colored clastics, 60 feet thick, of limited area at Mountainville on saddle between Saucon and Great Valleys, resting on quartzite.

C. Matrix of silt, red, yellow, brown, carrying the local outcrop, but firmer than it. Pieces angular at South Bethlehem. Ten feet thick at Bethlehem and contains limestone also. Found on the above saddle, and there more sandy. Shown in Figure 8 on col back of South Bethlehem, gneiss sand and a few foreign inclusions. On the crest of Kittatinny Mountain a slightly larger percentage of rolled pieces are found. Over the slate belt the matrix is more or less decayed slate. At Shoemakersville the slate flakes are firm and include polished sandstone boulders (Figure 12). In many places it seems to be the old surficial mantle overturned (Bethlehem, Center Valley).

D. Lateral moraine. Found along the northern flank of South Mountain west of Alburtis, full of cobbles, mainly of quartzite. Carried on to the limestone valley floor by settlement of stagnant ice towards valley trough.

E. Skeletonized rock trains (moraines?). One series extends from Klinesville northeast to Jacksonville and thence at an angle to Lowhill, south of Kittatinny Mountain. Three lines extend across Saucon Valley between Friedensville and Bingen, the largest 75 feet broad and 10 high.

Late Great Valley Period

Water-laid Drift. Glacial Outwash. Drumlins. Kames

These formations are found below 500 feet above ocean level, as the regional ponding never extended above that elevation. They are thus distinguished from the postglacial slope washes which are found at all elevations. Instead of this capping they are covered with an iceberg clay (see Packer Clay below).

As they are all connected with the ablation of the stagnant ice-sheet this name is suggested for their divisions.

Early Ablation Division. *Strong Currents*

Formation of narrow channel in the ice between Lehigh Gap and Easton, *via* Slatington and Bethlehem. Scour of rock floor and removal of most of the drift-sheet. Current too strong for deposition of coarse gravel. Icebergs abundant, and deposits only of boulders and masses from their collision or melting. It is probable that the second part of this division is much later than the first, and was laid after a broader channel had been cleared and an extension made over the northern edge of Fountain Hill.

A. Boulders sporadically distributed against the decayed rock floor in the East Allentown gravel working. Usually average 6 inches diameter, but are found up to 12 to 14 inches. Frequently the deposit is so thick (2 feet) that it is left unworked. The stratified gravel is removed by machinery to its top, and the remainder of the sands cleared away by hand.

B. Masses of Kittatinny rocks against the decayed limestone floor on northern edge of Fountain Hill, in sizes up to 11 × 4 × 4 feet. At least 10 feet thick, as bottom was not reached in excavation. Evidently an eddy deposit, as it is localized to a small area.

Late Ablation Division. *Medium and Variable Currents*

No increase in the volume of the stream, but enlargement of channel between the ice-walls, and thus reduction of velocity. The gradual broadening of the channel brought more rapid ablation, so that the velocity was not greatly diminished during this division till the area below 500 feet above ocean level was cleared of ice. Infrequent larger pieces from iceberg carriage.

A. *West Bethlehem Gravels.*—Assorted sands and fine gravels with few pebbles and infrequent cobbles laid in wavy strata which thin out towards the east, where they came within the influence of the Monocacy flow from the north. At this eastern end the strata are in foreset beds (see Figure 14). Thickness 10 to 12 feet; at Twelfth Avenue, West Bethlehem, 120 feet—both parts of a bar 4 miles long with top +160 feet above the rock floor. Another long and thick bar at Northampton Heights is cut through by the Philadelphia & Reading Railroad in passing about the east end of South Mountain. Numerous Kames are parallel to Lehigh River on the inside of curves in which are rock masses weighing tons (iceberg carriage).

B. *Lehigh Quicksands.*—Clean quicksands without inclusions ending on top in the most impalpable rock meal, fresh color, up to 5 feet thick. Absent at Rauch's Pit, owing to proximity to the Monocacy current. The above thickness at Twelfth Avenue, West Bethlehem. The Emaus drumlin belongs here, laid in conical strata from a center, as on a convex buddle, composed of fine material that could be carried by a strong wind, mainly fine sand.

C. *Current of Clear Water. No Deposition.*—End of the Removal of bergs from the cleared periphery of the stagnant ice. No icebergs or ice-cakes. Slight sculpturing of the east end of the gravels in Rauch's Pit. See Figure 14 for the difference in dip of the stratified gravels and their junction plane with the overlying clay. This is possibly due to the beginning of the trenching of the Monocacy gorge through the limestone roll of Bethlehem hill.

Lobe No. 2.—Broad Mountain Drift

EARLY BROAD MOUNTAIN OUTWASH. ICEBERG CLAY

This is found only in the portion of Lehigh Valley south of Mauch Chunk, and it attains its greatest thickness along South Mountain. The structure of the deposit indicates a levitated silt unmixed with vegetable material, and retaining the dark red of the surficial mantle from which it was derived. It carries sporadically abundant large angular pieces dropped from icebergs at all angles into the deposit. These extend beyond the series found in the drift of No. 3 lobe, and include micaceous sandstones of the coal, and partly decomposed pieces of anthracite. It is therefore derived from the Lehigh headwaters, and the large pieces are brought by ice-cakes. This indicates the arrival of No. 2 over the Lehigh headwaters. The absolute quietness of the flow is shown by the impalpable grains of the clay, which is levitated from the coarse sands, and over large areas is clean and worked for brick-making. There was thus no great increase in the flow of Lehigh River from the advent of No. 2. The level of ponded water is about 500 feet above ocean level south of Kittatinny Mountain, and is slightly above this north of the Lehigh Gap. The ponding is evidently due to clogging of the narrows of Delaware River, south of Riegelsville by bergs, as No. 2 was crossing that stream on its way over the Moosic-Pocono ridge. The ice-cakes were small, and the inclusions in the clay of moderate size. The latter are usually rough, and came from the decayed outcrops of the Upper Lehigh Basin.

A. *Packer Clay.*—The name is given to this deposit in Glacial Lake Packer. An iceberg clay, deep red in color, found generally below 500 feet above ocean level. Laid in current of less than 3 inches per second. Thickness 2 feet near main current, 28 to 30 at Twelfth Avenue, West Bethlehem.

BROAD MOUNTAIN GRAVELS. OUTWASH

B. *Upper West Philadelphia Gravels.*—These resemble the flood-plain gravels along Little Schuylkill and Schuylkill Rivers. The lower gravels seem to belong to the Early Great Valley Period of No. 3.

NOTE.—There is no other division thus far made of this drift, or of the deposits of the other lobes. No arrangement will be made here; but the variations will be noted in the descriptions of the various areas.

NORTHWESTERN PENNSYLVANIA

OROGENIC BEDS—PREGLACIAL

See definition at beginning of scheme. As slope washes and valley fillings. Thickness from 10 to 125 feet. Abundant outside of the glacial border, and form extensive beds below 1200 feet above ocean level, along streams away from the glacial outwashes.

FLUVIATILE DRIFT

EARLY FLUVIATILE. OUTWASHES

Strictly speaking the earliest of these came from the action of No. 8 in moving up Genesee Valley, but its distribution and deposition was in water ponded by the southern margin of the main trunk, and thus the formation falls under the above heading. Deposited from streams with moderate velocities. The beds are found against the rock floor, on quicksands, and on *orogenic* beds. The same kinds of deposits are found interstratified with later deposits, as the agencies that formed the materials continued till the end of the glacial advance.

A. *Conewango Clay.*—An unstratified, sticky, blued clay including wood fragments and logs. Found along the discharge from Glacial Lake Genesee *via* Cuba pass, Olean, Salamanca, Kennedy and Warren towards Barnesville. Varies in thickness from a few inches at Sheffield to over 200 feet. Not distributed generally over the ponded water of the region. Free from sand and inclusions.

B. *Lower Indian Hollow Sands.*—Very fine interstratified quicksands and fine sands with sandy clay lenticules. The sands are perfectly assorted and without inclusions; the lenticules contain sands, gravel (angular), pebbles and cobbles dropped from icebergs. Studied at a section in the deposit at Indian Hollow, opposite East Warren. See Figures 40, 41, 42, 43. Thickness there 60 feet, dip 17° to the south, foreset bedding thinning out down the dip. Also at State Line, 125 feet thick. Also at Glade and Clarendon. At the latter place 40 feet thick for this and the next bed.

C. *Stronger Current. No Deposition.*—The current quickened sufficiently to level these fine sands along a horizontal plane 1315 feet above ocean level.

D. *Upper Indian Hollow Sands.*—Horizontally stratified coarse sands and fine gravels laid in horizontal wavy strata. Fresh appearance, 20 feet thick. One stratum shows plunge-and-flow bedding. Upper surface at 1336 above ocean level. Figures 44, 45. Found also at Glade and Clarendon.

MIDDLE FLUVIATILE

The lateral margin of the Main Trunk had arrived sufficiently near to drop its burden on the spots where we now find the deposits of this period. They are thus laid above or below the level of ponded water of the region. But, as the ice-sheet covered its northern portion before it reached that to the south it follows that the northern drifts and outwashes are the older of the two series, but without superposition upon those most southern.

LAND-LAID DRIFT. All above the level of ponded water of the region.

A. *Garland Type.*—On hill-top near Garland. Red silt including angular slabs of the local outcrop. One crystalline pebble found imbedded in the mixture.

B. *Kane Type.*—On surface of plateau and along Kinzua Valley sides. Sand including flakes of local rocks, angular cobbles, boulders and masses of sandstone up to 12 × 12 × 4 feet. Found on top of stratified sands, discoidal gravel and clay.

C. *Brandon Type.*—A thin wash like the last, sandy, carrying rounded boulders of sandstone up to 3 feet in diameter.

D. *Foxburg Type.*—Like Garland Type. Red silt carrying rolled crystalline pebbles and cobbles. Coal fragments carried up hill above the outcrop.

OUTWASH. In ponded water.

A. *Clarendon Gravels.*—Stony gravel in wavy foreset bedding varying from nearly horizontal to 17°. Varies in proportion of foreign and rolled pieces. Thickness 40 feet. Forms the moraine at this place measuring over 1000 feet along a cross-section. Found also at Indian Hollow on top of the same stratified sands extending over 2200 along the hill slope (100 feet vertical). Also formerly filled the basin of Hook's River. Preglacially rusted. Limonite hardpan beneath from leaching of rust. Fig. 46.

LATE FLUVIATILE

This belongs to the interval between the ending of the glacial activity and the clearing of the troughs of the stagnant ice through which the torrential discharges could escape. This is the epoch of the beginning of the trenching of Big Bend col. The following beds were laid in the channels cleared through the stagnant ice, and thus bear to this portion of the ice-sheet the same relation that the West Bethlehem gravels do to No. 3, with the exception that the materials are derived mainly from fillings of the neighboring basins of the Clarendon gravel epoch. They are redistributed gravels with admixtures of local pieces.

WATER-LAID DRIFT. In ponded water.

A. *Early Big Bend Gravels.*—Similar in appearance to the Clarendon gravels, and swept from Dutchman's Run, Hook's River, Glade and vicinity. Laid in dipping foreset bedding in a long bar extending on to the plain at South Warren. Oakland Cemetery is located on this. Figure 47.

B. *Middle Big Bend Gravels.*—Later than the above. Big Bend col trenched to enable the scour to sweep out the filling of the Salamanca-Kinzua portion of the present Allegheny River channel. Varies considerably in crystallines and clastics from the last. Forms the long and lower bar at South Warren used as a railroad gravel pit. Figures 48, 49, 50, 51. There were three divisions of this sedimentation:

Ba. Coarse gravel and pebbles with little sand. Pebbles 3 inches in diameter. Wavy horizontal strata, extends from 5 feet above car track to unknown depth.

Bb. Lenticular sandy streaks lapping over like shingling, nearly horizontal, 3 to 4 feet thick.

Bc. Small assorted gravel in foreset bedding, dip 17°. Thickness 10 to 12 feet.

Bd. Increase in current so as to level horizontally the top of the above deposit. No deposition.

C. *Late Big Bend Gravels.*—Unassorted gravels with abundant boulders (iceberg) in foreset bedding forming the top of the gravels in the South Warren bar. Thickness 18 to 20 feet.

Ca. Increase in current so as to level the top of this bed. No deposition.

D. *Leverett Boulder Clay.*—A sandy clay with abundant boulders of larger sizes than in the uppermost gravels. Figure 48 shows the shelf on top of these gravels from which this clay has been removed. The long pile of boulders on this side of the cars is taken mainly from this. 8 feet thick here. Varies elsewhere from 2 to 8, and in the south is more sandy and quite free from iceberg burden.

NOTE.—Mr. Charles Butts (Warren Folio) places all these formations about Warren in the "Kansan or pre-Kansan" period. There is thus an agreement as to their age.

THE ATTENUATED BORDER

CHAPTER V

GREAT VALLEY DRIFT. LOBE NO. 3

The **Champlain-Hudson-Delaware-Schuylkill Lobe** moved with the glacial drainage down a valley with low trough trenched into Cambro-Ordovician rocks. The highest outcrop along its borders is Pocono. Abundant rolled pieces met it at the Delaware River crossing. Incorporated in it were icebergs from Professor Spencer's Laurentian and Erigan rivers which brought native copper and crystallines. This was the earliest of the lobes to reach Pennsylvania, and thus it left the oldest drift. The area covered by No. 3 is thus divided:

FIG. 4.—Reddish silt including local and foreign gneiss, Riegelsville, Nhn. Co.

Durham and Reading Hills.
The Great Valley.
Glacial Lake Packer and the Glacial History.
Kittatinny Mountain.
The Lower Helderberg and Marcellus Valleys.

The first three divisions have been treated before (see preface note, B and C), and only a brief treatment of the first two will be attempted. For topography see quadrangles of Easton, Allentown, Slatington, Reading and Hamburg. For the geology see the 4-sheet map of the last state survey.

Durham and Reading Hills—The South Mountain.—Figure 4 shows the drift-sheet at Riegelsville, west of the town and above the Delaware gravels. It is from 10 to 15 feet thick, and carries boulders of dark hornblende gneiss up to 2½ feet in diameter. Over Rattlesnake Hill it carries cobbles of local gneiss 9 inches in diameter. Native copper has been frequently reported east of Saucon Valley.

Saucon Valley.—Figure 1 shows the drift-sheet in a railroad cutting south of Bingen station. Figure 5 is where Saucon Creek cuts through the southernmost of the rock trains southwest of Bingen. The mass is of gneiss from the crest of South Mountain. The woods indicate that the tract is too stony for cultivation. Figure 6 is on the side of a rail-

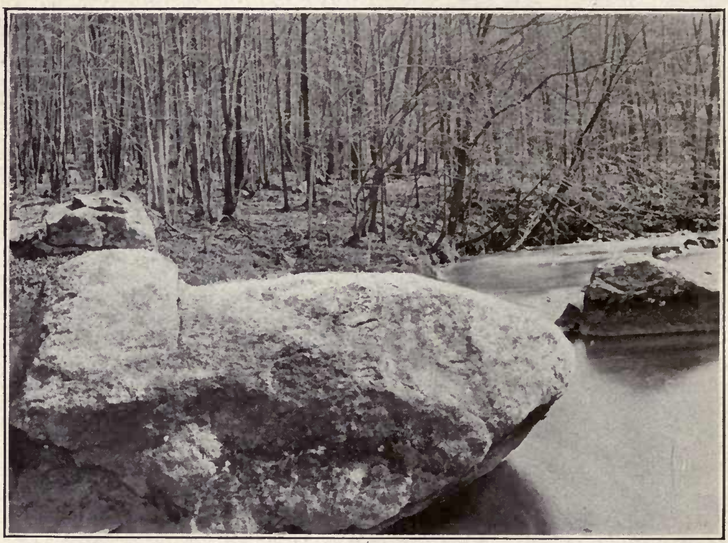

Fig. 5.—Moraine traversed by Saucon Creek, near Bingen, Nhn. Co.

road cutting ¼ mile south of Center Valley. The red silt includes quartzite, Triassic shale, angular gneiss. This is below the level of glacial Lake Packer. Figure 7 shows a mass of Oriskany sandstone on the side of the Philadelphia Road at Friedensville. Note the rough quarry-face and the casts of *spirifer arenosus.* The piece was brought over Kittatinny Mountain, across the Great Valley and over South Mountain. The other rocks are mainly from Kittatinny Mountain.

The southern part of this valley should be carefully examined, as it seems as if the old surficial mantle has been stirred by an ice-sheet that brought nothing to the mixture. This is seen 1 mile south of Coopersburg, and between this place and Limeport, above the level of glacial Lake Packer (500). The boundary of the Attenuated Border can be drawn from Monroe, on Delaware River, so as to include Durham Valley and the cove of Saucon Valley about Coopersburg, thence to the rise west of Friedensville and along the mountain flank south of Mountain-

FIG. 6.—Brownish-red silt including quartzite, gneiss, Triassic red shale, railroad cutting south of Center Valley, Nhn. Co.

FIG. 7.—Mass of Oriskany sandstone showing casts of Spirifer arenosus, Friedensville, Nhn. Co., part of moraine across Saucon Valley.

ville, where 60 feet of gravel (Early Great Valley B, see scheme) are found. Figure 8 shows a Lower Helderberg pebble (under the arrow-point) in a drift sheet of gneiss sand on the col of South Mountain between the last named place and South Bethlehem. Figure 9 is angular

Fig. 8.—Lower Helderberg pebble (beneath arrow) in gneiss sand on col of South Mountain southwest of South Bethlehem, Nhn. Co.

Fig. 9.—Pile of trap cobbles taken from drift of gneiss and quartzite, near crest of South Mountain, South Bethlehem, Nhn. Co.

local drift of great thickness on South Mountain worked for sand. The pile of cobbles in the right foreground contains rounded pieces of trap.

West of Mountainville the ice-sheet did not cross South Mountain, but its lateral moraine gradually accumulated until west of Topton it was composed of abundant cobbles of gneiss and quartzite intermixed with gravel and angular local pieces. This was somewhat incorporated into the margin of the ice which, during the ablation and settlement towards the valley trough, settled away from the mountain and on to the limestone plain, so that some of this drift is separated from the wash down the slope by a slight ridge parallel to the mountain. This is seen west of Topton. The drift from Alburtis westward varies in thickness along the mountain flank from 20 to 120 feet, and many cuttings through it were made by the railroad between Allentown and Reading.

As the trend of South Mountain changes to the south at Blandon, this drift accumulation leaves its flank and grows thin as it nears the Schuylkill River and the front of the ice-sheet.

The Great Valley.—The peculiarities of its drainage on either side of Lehigh River have been described, with a map (see preface note B). The new features to which attention should be called are the Emaus drumlin

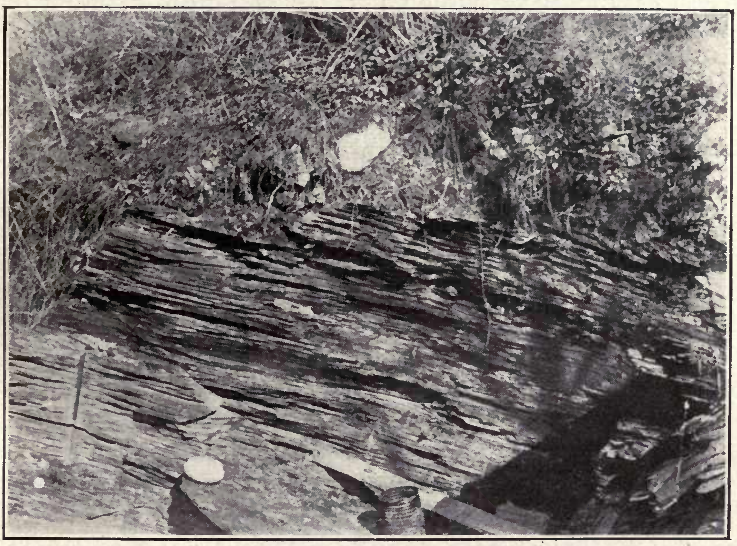

FIG. 10.—Merchantable slate beneath drift, Siegfried's, Northampton Co.

which Professor Benj. L. Miller discovered in his work about Allentown. This has been noted in the glacial scheme (Late Ablation, B, Late Great Valley Outwash). It stands so entirely away from the flank of the mountain that it can not be a slope wash. The materials are fine enough to have been blown upon the glacial surface by winds. It was formed by a slight trickle down a crevasse. There is nothing up to ¼ inch diameter in the body of fine silty sand. The foreigners are specks of quartz veinstuff from the slate and of chert from the limestone. It is capped by the usual dark red silty Packer Clay carrying the usual iceberg burden of pebbles and cobbles of considerable size. The unstratified dark clay cap is entirely different from the body of stratified fine sand which slopes everywhere from a central axis as if laid on a convex buddle.

The quarrying of merchantable slate immediately beneath drift has been mentioned in previous publications. Figure 10 is from a quarry 1 mile west of Siegfrieds Station. The solidity of the slate under the drift is well shown. This indicates that from 60 to 80 feet of surficial decayed mantle have been removed, as that amount is usually "mucked" from an unglaciated slate body before merchantable slate is reached.

Attention is called to the extraordinary distance that the 500-foot contour (see Hamburg quadrangle) has been trenched into the northern slope of Kittatinny Mountain by the headwaters of Ontelaunee Creek—a greater distance than anywhere else in the vicinity. This will be again considered when we describe this mountain. The drift-sheet of this region is monotonous, as the ice-sheet moved parallel to the strikes of the outcrops, so that slate was picked up by the ice and dropped on slate: the Hudson sandy beds on similar outcrops: limestone on limestone. There is little other than the infrequent erratics from other formations to tell that this is drift over the valley floor. Near the streams are bodies of partly rolled gravel, rounded cobbles and boulders that appear to have been developed by spheroidal weathering. It is only by finding unmistakable drift beds farther west that we appreciate that this portion has been covered by the ice. Apparently, it has not been at all *glaciated*, in the old acceptance of the term.

On the third crest of the Maiden Creek-Schuylkill watershed, 3½ miles east of Hamburg is a drift-sheet of unknown thickness, consisting of slate flakes and slabs including Oneida and Medina gravel, cobbles and boulders, and overlaid by 5 feet of reddish sandy silt including rusty local angular rocks and small pieces of Oneida and Medina. As this is on the top of a crest it is not a wash. The boulders are traced towards the Schuylkill and are mainly subangular and rough, spheroid, ovoid, some waterworn, some old and surface-cracked. They finally disappear before reaching the river, and therefore do not come from thence. At Hamburg the slate outcrops vertically beneath a cap of river gravel, not at all like the drift 3½ miles to the east.

Between Maiden Creek and Shoemakersville, however, the drift-sheet is carried continuously to Schuylkill River. Wells at this place pass through 12 feet of "Schuylkill River Bottom" and 10 feet of "gravel" to reach the slate floor. It is but 10 feet thick, and most of the wells stop in it so as to find soft water, while others pass through it and end in the limestone. The tip of the tongue of No. 3 crossed the river between this place and Hamburg. Figure 11 shows the slate decayed and outcropping vertically. This is in a railroad cutting which exposes no hard slate. Three hundred feet south a channel has been broadly

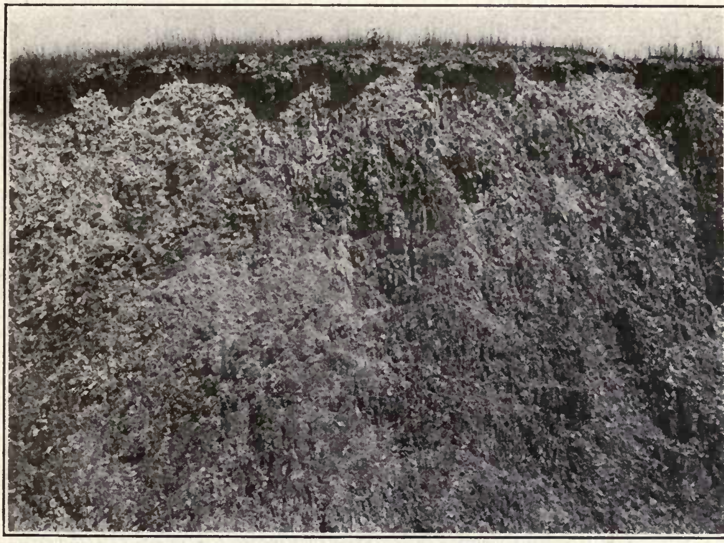

FIG. 11.—Cutting in Hudson slate decaying in place, between Shoemakersville and Hamburg, Berks Co.

FIG. 12.—Cutting in drift of slate flakes enclosing polished sandstone boulders and cobbles, 300 feet south of last figure, Shoemakersville, Berks Co.

scooped into this soft bed and filled with land-laid drift, as shown in Figure 12. The body of the drift is of slate slabs and flakes with little or no sand, including glaciated and polished sandstone cobbles and small boulders. At times this carries sporadic bodies of rolled gravel, and in places it is capped thereby. This is an unstratified land-laid drift with materials brought from the eastward. On the west side of the river, opposite Shoemakersville is a cutting through the capping of a slate quarry. It shows large and small slabs lying at all angles north of Centerport, Figure 13, and indicates the removal of a considerable cap of decayed surficial mantle.

Attention is called to the need of study of the valley of Tulpehocken Creek, which debouches upon the Schuylkill Valley at Reading. The

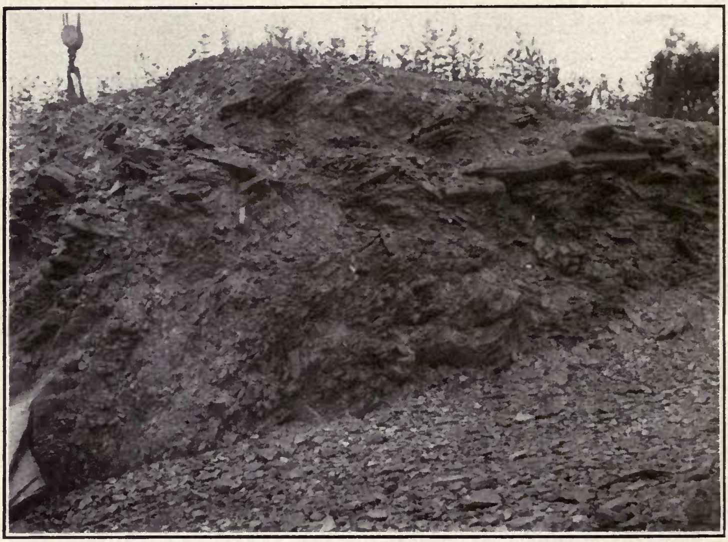

Fig. 13.—Drift at extreme edge of ice-sheet, Centerport, Berks Co.

portion of interest is its branch called Northkill Creek, which rises below Northkill Gap, 5 miles west of Schuylkill Gap—both in Kittatinny Mountain. Mr. Barrell reported that the flood-plain contains rolled water-worn and semiangular Medina and red sandstone (Hudson) cobbles up to 6 inches in diameter which could not be traced over 50 feet above the creek. The soil is the usual aggregate of slate flakes without gravel. If the cobbles were distributed by water there should be sand and silt in the mixture, and perhaps gravel.

Glacial Lake Packer and the Glacial History.—The area can be found by marking the 500-foot contour of the Easton, Slatington and Allentown quadrangles. The restraining col was at Topton, about 495. Leithsville col was covered by the ice-sheet. The Delaware narrows below Riegelsville was closed either by the ice-sheet or, after that was stagnant, by icebergs from No. 2, which was crossing the river above Stroudsburg.

The lake level is marked by the stopping of Packer Clay (Early Broad Mountain A) at or about 500 near White Hall, Jacksonville (Northampton Co.), Bath, Laury's, Bowman's and Parryville. North of Lehigh Gap it extends slightly above 500. At Parryville it is overlaid by outwash from No. 2, and is thus not an outwash from the great moraine, but belongs entirely to the First Phase, as does the entire history of this lake, which had three periods:

First Period.—Preglacial Flooding.
Second Period.—Glacial Occupation.
Third Period.—Clearing of Stagnant Ice from the Lake Area.

First Period. Preglacial Flooding.—No deposits other than *orogenic* slope-washes have been found. The flow in the Lehigh and affluents would be that of an abnormal spring thaw. This period might be a long one, as clogging of Delaware narrows would begin as soon as bergs could reach it. The glacial ablation came with No. 3, and the latter reached Port Jervis and the Delaware trough, 55 miles above the Mouth of Lehigh River, where bergs could be calved readily, centuries before the glacial front arrived at Easton. This time should be sufficient to leave records of ponding, were it not for the covering of the lake bed by ice, and the subsequent scour that reached to its rock floor.

Second Period. Glacial Occupation.—To cross Kittatinny and South mountains the ice-sheet at Easton must have been 1250 feet thick and 1000 at Allentown, with average weight of 35 tons per square foot of surface along the Lehigh trough between those places. The drift of this period has been named *Early Great Valley.* From a study of the profile of the trough of Lehigh River between Mauch Chunk and Easton it is possible that it has been trenched 40 feet at Allentown. The fall between the first and Lehigh Gap is 7.5 feet per mile; thence to Allentown, 10 feet; thence to Glendon, 4.23 feet; thence to Easton 7.5. An average grade of 7.5 between Mauch Chunk and Easton would elevate the bed at Allentown 40 feet. That is the depth of the drift filling at South Bethlehem (Steel Works), and as the trench walls between New Nisky Cemetery and the limestone outcrop south of the Steel Works rise over 20 feet above the river bed, the Lehigh trench there is over 60 feet deep, and with steep walls. This trenching may be merely the crushing of the roofs of a series of caverns along the outcrop of the limestone immediately adjacent to the Lehigh trough between Allentown and Easton, and along the flank of South Mountain west of Allentown. These last have been broken in and filled with drift varying in thickness from 20 feet at Alburtis to over 89 at Topton, with greater thicknesses farther west. From these caverns much of the limonite has been taken, and in them there is the same sequence of drift sheets that obtains on the surface of the limestone valley (preface note B, p. 296). In connection with this trenching of the Lehigh trough is the discovery of the preglacial bed of the Monocacy against the granulite rock floor at Twelfth Avenue, West Bethlehem, 160 feet below the crest of the hill, and far below the present water level. This would indicate a discharge into Lehigh River at the great bend near Geisingers, and would also be in accord with Mr. Barrell's suggestion that Lehigh River long before the glacial period passed through Leipert's Gap in South Mountain into the Perkiomen-Schuylkill basin. This flow may have been at the time when there was a river flowing through the Wind Gap. A study of this region, however, may connect this Gap with the advent of No. 3.

Third Period. Clearing of Stagnant Ice from the Lake Area

Late Great Valley Drift. Early Ablation Division. Strong Currents. —In the scheme, the strength of the currents was laid to the narrowness of the channel torn through the stagnant ice. This seems to be substantiated by the intensity of the scouring of the rock floor and the removal of the land-laid drift along the current lines. Had the strength of current depended upon a possible increase of snow-cap incident to the arrival of No. 2 over the Lehigh headwaters there should have been a continuation —even an increase—in that strength as the lobe itself gained and covered the same. On the contrary, the strength of current diminished and at the end, when No. 2 actually covered those headwaters, the slackest current on record obtained, as will be seen by the increasing fineness of the grains in the deposits. This decrease in current velocity can be associated with increase in current volume if the cross-section of the channel increases more rapidly than does the latter. The conclusion is thus forced that the channel torn through the stagnant ice was broadened by the erosive force of the current aided by the calving of the margin into the open area as the ice-sheet, during ablation, settled towards the regional trough.

This current through the gradually increasing area of clearance would have dropped its bulky burden at Mauch Chunk as soon as the level of ponding was reached. The deposits of the time are therefore disassociated with No. 2 and influences north of that Gap, and confined to the decaying ice-sheet. This is the reason for calling the following "Ablation" divisions.

The Deposition of Rock Masses and Boulders.—The line of current seems to have passed north of the granulite hill opposite Allentown on the east bank of Lehigh River. Later there seems to have been a clearance over the present river channel, and a current south of this hill also, with a long line of slacker water just east of the hill, as obtains below each pier of a bridge. This current took a short cut from Catasauqua to Bethlehem north of Rittersville. It would strike South Mountain over South Bethlehem, and probably cleared away the stagnant ice there over an area extending westward to include the end of Fountain Hill immediately west of the Episcopal Church, where there seems to have been an eddy.

The discovery of the accumulation of boulders that "splashed" into the preglacially decayed rock floor at East Allentown has been told in chapter four. They were dropped at this time. While their sizes tell only of ice-cakes of moderate size, there are large masses found near the bottoms of the kames along the Lehigh banks that tell of larger bergs, and especially on the edge of Fountain Hill is a pile of large masses at least 10 feet thick, one of which measured 11 × 4 × 3 feet. These seem to have been dropped by the grinding of bergs, or their collision, rather than by ablation. We can picture the surface of the stream covered by bergs and cakes which were hurried to the clogging in the Delaware narrows. There was not a sign of clogging in the Lehigh channel. The water was at least 250 feet deep over the decayed floor at East Allentown. The boulders that "splashed" into its soft surface did so at an angle of 40° with the vertical, and thus showed a swift motion in the ice-cakes from which they were dropped. This period was followed immediately and without unconformity by the

Late Ablation Division. Slackening to Slow Currents.—The channel south of the East Allentown granulite hill seems to have been cleared away at this time and a strong current passed there, while there was an area of slackened water 4 miles long behind that hill, extending from it to the present Monocacy channel between Bethlehem and West Bethlehem. The current south of the granulite hill dropped cobbly drift between Allentown and South Bethlehem, resembling that of Figure 3, dropped under exactly similar conditions where Glacial Lake Lesley was discharging its waters similarly filled with ice-cakes over the col at Dix, Blair County, but differing in being better rolled. They can be seen in the many cuttings along Lehigh Valley Railroad. The currents were over 12 inches per second and less than 4 feet. Behind the granulite hill they varied between 6 and 11 inches per second, and dropped in wavy layers interstratified sands and fine gravels—both free from silt and clay—in which were dropped very infrequent small cobbles and at long intervals apart a small boulder. Figure 14 shows the working face at Rauch's Pit in 1897. The Monocacy gorge is ⅛ mile to the right, and the influence of its current is seen in the foreset dip of the gravels to that side and the subsequent smoothing along a plane dipping to the right. The pile of small cobbles in the foreground is of rolled pieces dropped by ice-cakes. An examination of the working face shows no boulders. The writer has notes of less than 6 during 25 years of examination. Mr. Lesley used this absence of boulders to attribute this bar to an old "high-level" river bed (Letter of transmission, vol. D3. 2d. Geol. Surv. Pa., 1878). At Twelfth Avenue, West Bethlehem, slightly below the crest of the formation, a well was driven 160 feet through it to reach the granulite rock floor below the present Lehigh water level.

Another point of interest of this division is the almost equally huge bar extending eastwardly from the end of South Mountain, on which Northampton Heights is built. Figure 2 is taken from the track at the bottom of a deep cutting where the Philadelphia & Reading Railroad passes about the end of the mountain. The depth of the cut can be measured by noting the height of the telegraph poles. This track level is 100 feet above the Lehigh River. The Lehigh channel immediately opposite this is filled with drift for 40 feet. The top of the bar is thus at

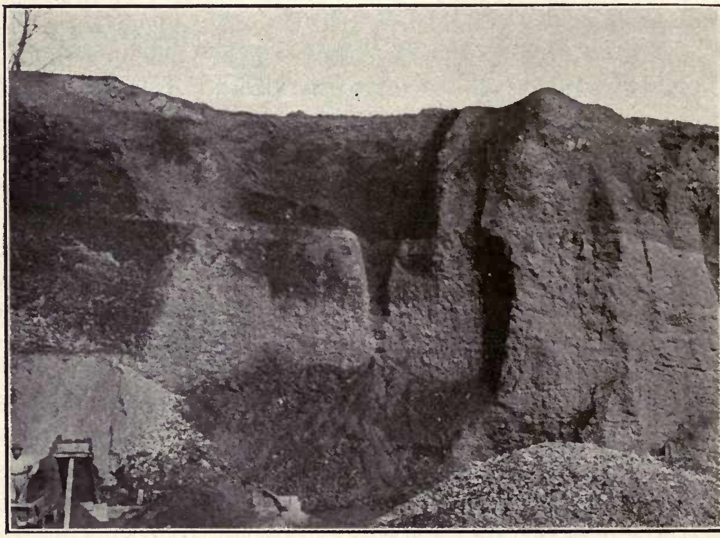

FIG. 14.—*West Bethlehem gravels* overlaid unconformably by *Packer Clay,* Rauch's Pit, West Bethlehem, Lehigh Co.

least 200 feet above the rock floor of the Lehigh. The gradual shading of thickness of strata and of sizes of pieces from the center line of this bar to the Saucon Valley to the south, and the Lehigh Valley to the north, indicate an equally strong current from each moving towards Easton. This, in turn, proves that the Leithsville col at 450 was covered by the stagnant ice, and that there was no movement of current from the Lehigh into Saucon Valley. This condition continued through the ablation of the stagnant ice, and will be referred to below.

It remains to speak of the character of the gravels and sands dropped during this division. There is an inch of limonite hardpan (see preface note B, p. 291 and Figure 11) beneath the gravels at Rauch's Gravel Pit, showing that the gravels here were either preglacially stained or were affected by the seepage from the highly ferruginous Packer Clay above. There is no impervious stratum above them here, and the latter suggestion is the correct one, as, at Twelfth Avenue, the same gravels are capped by 4 to 5 feet of quicksand and rock meal of light color and impervious character, on which are from 28 to 30 feet of the above clay. The writer sank a shaft for a sewage opening over 70 feet into the bar, through 28 feet of clay, 5 of quicksand, and 40 feet into the stratified gravels, which were as clean and fresh as those in the Lehigh river bed. The gravels were thus clean when laid down. These gravels and the overlying quicksands at Twelfth Avenue, above are the *Late Ablation Division, A and B,* of the Scheme, and the smoothing of the top of the gravels in Rauch's Pit referred to immediately above is the part *C* of the same.

Broad Mountain Drift. Lobe No. 2.—We now come to the evidences of the arrival of No. 2 over the headwaters of Lehigh River after the clearing of the basin of Lake Packer from ice and the passage of clear water to smooth the surface of the upper of the deposits from the ablation of the ice-sheet. This is in accord with the calculation made in chapter two, where, with a maximum advance of 100 feet per annum, No. 3 would reach its farthest bounds over 9000 years before No. 2 would pass the Lehigh watershed, or eliminating the rate, it would take No. 3 six-elevenths of the period to reach its farthest extension that No. 2 would require to cross the above watershed. This would allow for a sufficient extension of the activity of No. 3 to bring to the Saucon Valley the three rock trains, the most northern and latest of which would reach its present position about 1000 years after the arrival of the front of the lobe at Schuylkill River. This period of activity would be sufficient to hollow the Punch Bowl out of the southern flank of Kittatinny Mountain near Bake Oven Knob.

Early Broad Mountain Period. Outwash. Packer Clay.—This brownish-red sandy silt covers everything in the Lehigh basin below 500 feet above ocean level, and is absent from Saucon Valley—being there replaced by a thick slope-wash near the bordering hills, and a thinner wash over the valley floor. The Saucon wash varies from that in the Lehigh Valley both in its lack of thickness and in the absence of the iceberg inclusions which abound over the Lehigh basin. The increase in volume which obtained north of Lehigh Gap was insufficient to produce over the general line of flow through the ponded area of Lake Packer a current greater than 3 inches per second. This in itself indicates a large cleared area and a movement of water towards the Delaware extending from Nazareth to Emaus, or entirely across the flooded area. The thickness of the clay varies from 6 to 30 feet. It is over 10 feet thick at Nazareth, 17 at Emaus, 30 to 10 over the West Bethlehem bar, 6 at Northampton Heights and Bethlehem. Figure 14 shows its thickness and appearance at Rauch's Pit, West Bethlehem, with the cobbles and small boulders scattered through it. Figure 15 is the face of the brick working north of Bethlehem and 1¼ miles northeast of the gravel

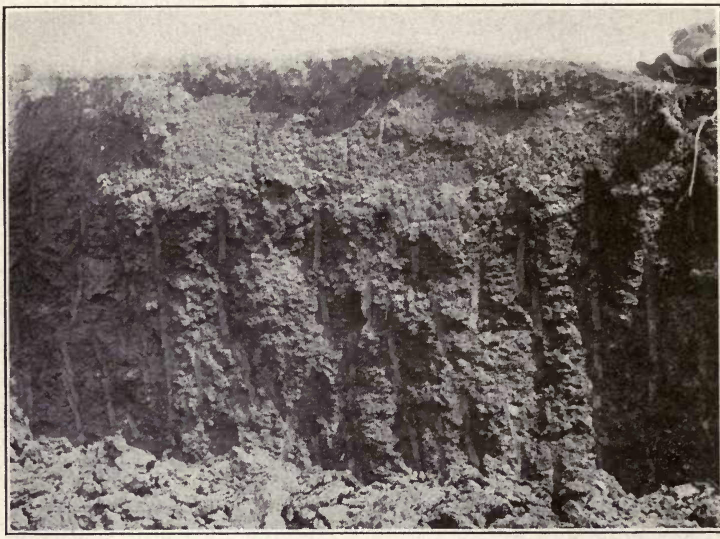

FIG. 15.—Packer Clay, Brick-yard, Bethlehem, Nhn. Co.

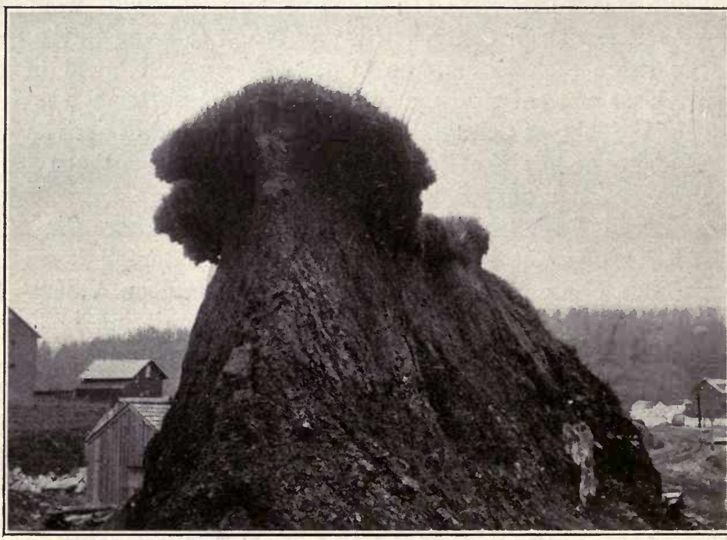

FIG. 16.—Packer Clay, Brick-yard, East Allentown, Lehigh Co.

pit. Here the clay is cleaner, but it contains pieces brought by ice-cakes, among which the writer found some fragments of the decayed anthracite outcrop which resembled the half-consumed pieces of the same after quenching and washing free from ash. This decay is not post-glacial, as the cracks and corrosions of the surface of the pieces were filled with clay, which was readily washed therefrom by a weak jet of water. The subject of decay in anthracite will be fully considered in the analyses of Morea coals. Micaceous sandstone from the coal is also found in this clay to prove that it is the levitated surficial mantle of the Lehigh Headwaters. No vegetable mixture is discernable, and there is, as far as known, no bluing of the clay through reduction of ferric salts. Figure 16 shows the fag-end of the clay cap at the abandoned brick working at East Allentown. Here it was 15 feet thick. Figure 17 is a section at Stemton, near Lehigh River, showing the rounded character of the boulders. The smoothed rock projection in the middle

Fig. 17.—Packer Clay, on kame, 60 feet above Lehigh River, Stemton, Nhn. Co., including polished Pocono cobbles (iceberg burden).

foreground is the fresh and glaciated limestone outcrop. Its covering by a gravel outwash at Parryville shows that it belongs to the First Phase, and is not an outwash from the great moraine. This is also substantiated by the cleanness of the clay in the filled sink-hole at Nazareth on the northern border of the limestone outcrop, and but 6 miles southwest of the great moraine.

Kittatinny Mountain.—This is locally called the Blue Ridge. It averages 1550 above ocean level, with a crest of Oneida conglomerate, with Medina sandstone immediately to the north of the crest, and with Clinton forming the lower half of the northern flank. The ice-sheet readily crossed this ridge in New Jersey as it was nearer the northern part of the trough in which No. 3 moved. West of Delaware River it was a dividing line one-fourth of the way from the Pocono to the Granulite ridges between which the lobe moved, and thus, with abundant room to the north, there was a change from the push over the ridge to a movement almost parallel with its crest, and thus with the strikes of the outcrops of the rocks that formed it. The huge masses of Oneida conglomerate south of it on the slate belt did not move directly south, but came from its crest far to the east. These are very abundant west of Slatington, and thin out till south of Bake Oven Knob one solitary mass is found. That there was a crossing of the ridge is proved by finding Oriskany cobbles and pebbles close against the southern flanks

Fig. 18.—Accumulation of Oneida conglomerate masses where working face of glacier crossed Kittatinny Mountain at Bake Oven Knob.

as far west as Wanamakers. This crossing was, however, at such a slight angle that the pieces picked up from an outcrop were left on the same farther west. Figure 18 shows such a heaping of the Oneida conglomerate at the crest of Bake Oven Knob, from which the gravels and sands have been completely removed. Figure 19 shows the crest west of the Knob, where there is cultivated soil. A well near the Mountain House on the road to Kepner is sunk 30 feet in gravel. On the southern flank the drift-sheet is almost purely local and angular. On the northern flank Oriskany cobbles are carried towards the crest on the Kepner road, and are found along that flank almost to Rene Mont. The ice was thus astride the crest within 3½ miles of Schuylkill River. The finding of the drift-sheet east of Hamburg shows the possibility of the extension of an ice-tongue into the wedge-end behind the Offset, if not into its lower loop, below whose opening the above drift was found.

The carriage of the 500-foot contour deeply into the southern flank of the ridge south of Bake Oven Knob has been noted above. It seems probable that a surficial stream from the glacier fell 1000 feet against this flank and hollowed the Punch Bowl as we find it today. That something extraordinary occurred within a small area is shown by the Punch Bowl, the deep trenching of the many affluents of Ontelaunee Creek and the 200 foot drop of 2 miles of the ridge crest. This region deserves careful study. It is possible now to draw the boundary of the Attenuated Border from the mountain flank south of Mountainville, on the saddle between Saucon and Great Valley, along South Mountain northern flank

FIG. 19.—Smooth and cultivated crest of Kittatinny Mountain west of Bake Oven Knob.

to Temple, where it passes across the valley in a loop enclosing Centerport, on the west side of Schuylkill River, and returning to pass around the Offset fault of Kittatinny Mountain and reach the crest of the latter 3½ miles east of Schuylkill River.

The Lower Helderburg and Marcellus Valleys.—These are bounded on the south by Kittatinny Mountain and on the north by Mauch Chunk (Pocono) Mountain. There is a slight Oriskany ridge and a more pretentious Catskill one west of Lehigh River, which is all of the region that will be considered, as the tracing of the boundary is all that will be attempted. The presence of native copper is reported in the eastern end of this region, in Monroe County, by Dr. Albert G. Rau of the Moravian College.

The Lower Helderberg (Lizard Creek) Valley is the deeper and contains throughout an abundance of rolled and sand-poor gravel of fresh

FIG. 20.—Railroad cutting through moraine west of Kepner saddle, Schuylkill Co.

FIG. 21.—Cobbles from gravelly drift, Balliet, Carbon Co.

appearance, which is cut through many times by the railroad. This disappears on the col at Kepner, and is therefore due to the ponding of Lake Packer. The moraine at Kepner is 1 mile west of that station, and the railroad cutting is deep, as shown in Figure 20. There is a steep slope westward to the Little Schuylkill trough with a wash upon it, which may overlie drift as elsewhere near the boundary of this and the great moraine. The railroad cuttings beyond Kepner show no gravel or any cap, but their tops seem to carry a thinner and a fresher capping than would obtain in an unglaciated region, and it is probable that the clear ice-front went farther west and south. Figure 21 shows the Lizard Creek drift at Balliet.

The movement of the ice-sheet parallel to the strikes of the formations makes the drift-sheet monotonous over the higher and more broken Marcellus-to-Catskill region south of the lofty barrier of Mauch Chunk Mountain. Pottsville conglomerate is found on a crest between Pennsville and Lehighton, which may have come *via* Lehigh River. More definite and convincing evidences of the passage of the southern margin of Lobe No. 2 over Mauch Chunk Mountain and upon the Catskill border will be described in the next chapter where this lobe is studied. It remains to say that in the land-laid drift of No. 3 no rocks have, thus far, been found above Pocono.

CHAPTER VI

BROAD MOUNTAIN DRIFT. LOBE NO. 2

The Champlain-Mohawk-Delaware-Shamokin lobe moved over the Delaware watershed, the eastern boundary of Pennsylvania, the Moosic-Pocono ridge, the Lehigh headwaters, the Middle and part of the Southern Anthracite basins, and stopped against Susquehanna River. From the outcrops crossed, the rocks to be expected in the drift-sheet extend from Cambrian to Pennsylvanian, but the crossing of the Mohawk and Delaware troughs twice eliminated the basal burden, so that within the Attenuated Border we find only the local Mississippian-Pennsylvanian fragments as the bulk of the drift, with extremely rare foreigners, such as limestone, and less rare shales near the Catskill. The rocks most common begin with the Pocono, which was at the top of the column in the drift of No. 3, and so the sheets of these two lobes differ almost completely. Of the local outcrops covered there are 360 square miles of Mauch Chunk red shale west of Lehigh River, and a total length of 84 miles of the same in the narrow valleys bordering the basins between the Lehigh and Susquehanna rivers, and yet there is not a large proportion of Mauch Chunk in the drift. The highest elevations are over the Pottsville conglomerate anticlinal north of Morea (2100), and the broad mountains are of the same formation. In fact, No. 2 crossed 14 Pottsville outcrops between Bear Creek and the spoon-end of Little Mountain

(Pocono), against which the tip of the lobe massed itself. The drift-sheet is thus mainly Pottsville with some red shale and the micaceous and other sandstones of the coal, and only the presence of these in inconsiderable amounts enables us at times to distinguish it from the decayed mantle over an unglaciated Pottsville outcrop. The area covered by No. 2 is thus divided:

The Southern Basin.
The Pottsville Anticlinal.
The Western-Middle Basin.

Before describing the glacial phenomena in these basins it is necessary to say that the wet preparation of coal has filled the streams and, when ponded, the valleys, many feet deep with culm, so that the old stream bottoms and valley floors are not only masked but obliterated. The old methods of working have permitted the anthracite outcrops to cave in. The monotonous Pottsville composition of the drift requires an absolutely fresh section for study, and such can be found only at the headwaters of the small affluents of the main streams. The tendency to slabbiness in the sandstones of the coal has rolled not only the rounded masses and gravel derived therefrom, but even the pebbles of the Pottsville conglomerate from the stream bottoms, unless ponding of water prevailed. In consequence, although the upper part of the West Philadelphia gravels passed through the streams of the Southern Basin which were covered by the ice-sheet, the regional stream-bottoms are almost everywhere slabby. Now and then they have been cut into a flood-plain containing boulders and gravel. The accurate marking of the boundary of the Attenuated Border is therefore more difficult over this region. Another difficulty results from the sheer rise of the two borders (Pocono and Pottsville) above the basins and their intervening Mauch Chunk Valley. These caught No. 2 within their grip and forced it to move along the strikes of the measures, so that the drift is locally monotonous, and its identification depends on the foreigners, or, where a ridge has been crossed, on the crestal blocks carried onward into the valley beyond.

The Southern Basin. *Panther Creek.*—This is the extreme eastern end of the basin and rests against Lehigh River, so that there is no doubt of its glaciation. The point at issue, however, is whether the edge of No. 2 crossed Mauch Chunk Mountain (Pocono). Masses of the Pottsville inner rim of the basin can be traced from Summit Hill across the red shale valley to within 100 feet of the outer Pocono rim, and masses of the latter and pieces of Pottsville are found in the 3-foot drift-sheet on the road to Bloomingdale at 1049 above ocean level. This sheet also carries micaceous sandstone of the coal and slabs and flakes of red shale, and can be found just east of Little Schuylkill Gap in Mauch Chunk Mountain. The drift of No. 2 thus intrudes upon that of No. 3, and settles the point queried in the end of the last chapter. The boundary of the Attenuated

Border can be drawn from the point on Kittatinny crest, 3½ miles east of Schuylkill River in a slanting direction so as to pass about the moraine west of Kepner, and almost to Rene Mont, and thence to the Little Schuylkill Gap just above mentioned.

Tamaqua.—The above Gap is less than 1 mile south of Tamaqua. The Mauch Chunk red shale on the east side of it is crushed southward by the ice. The ice-sheet ponded the water for 4 miles southwest of Tamaqua, so that for this distance to the divide beyond where are the headwaters of Schuylkill River, there is abundant rolled gravel, showing that the ice-sheet crossed the divide at Tuscarora. About Tamaqua are abundant evidences of glaciation, the best being the glaciated coal outcrop, opposite the railroad station, with gravel for a cap.

Pottsville Basin.—The Southern Basin is 1 mile broad at Tamaqua, 2 at Tuscarora, and 3 at Pottsville. The change from gravelly drift is not sudden on the divide. It is found both in the stream bottom and in the flood-plain at New Philadelphia, 6 miles beyond and but 4 from Pottsville. From Cumbola to the last the stream-bottom is slabby. Even below the debouchment of Silver Creek which flows over a drift bottom cut into a drift flood-plain it remains slabby, so that no value can be attached to the slabbiness. Silver Creek is trenched deeply into the Pottsville conglomerate anticlinal, rising near the highest point south of Bear's Head (1680), and 3 miles southeast of Morea. Its bottom is full of rounded boulders. The ice-sheet covered the area where Locust and Broad mountains meet. Leaving the question of how much nearer to Pottsville the ice-sheet came till later we now consider the broad area of the Pottsville anticlinal.

The Pottsville Anticlinal. Morea.—Reference is first made to preface note F, where the glaciation of the Morea region is described. Its many illustrations show the level planing of the vertical northern outcrop and the character of the drift. The movement southward of the ice-sheet must be borne in mind in connection with the fact that the margin of an ice-sheet is supposed to have little or no erosive power, and the amount of erosion which took place here tells that a great weight bore down on this region, and that the margin must have extended farther south, especially as the weighted portion which performed the erosion moved southward. Figure 22 shows the south outcrop of the Mammoth Bed planed level and covered by 8 feet of Pottsville conglomerate drift in which are boulders 5 feet in diameter. The character of the glaciated coal will be noted immediately below. The weight of the ice-sheet is shown by the high polish of large areas of conglomerate near Delano, 8½ miles north of Morea. Two miles south of the latter on the hillside south of the Eisenhuth Reservoir the same drift overlies the outcrop of the Lykens (A) Bed. In it was found a pebble of non-fossiliferous dove-colored limestone (?Beekmantown, Lowville, Pamelia?). The same drift is found 7 miles southwest of Morea where Mill Creek cuts through 5 feet of drift to join Schuylkill River, 865 feet below the elevation of Morea. Here the rock floor is red shale, but the drift is like that at Morea. The lowest foot of drift varies greatly, as will be seen by the three sections taken immediately over the Mammoth (E) Bed at Morea. The first two over the north outcrop; the third at the extreme western end of the spoon. The fresh and light-colored appearance of the drift is well shown in Figure 22.

Section 1 was taken three breasts east of the crossing of the Pennsylvania Railroad; 2, 200 feet east of (1).

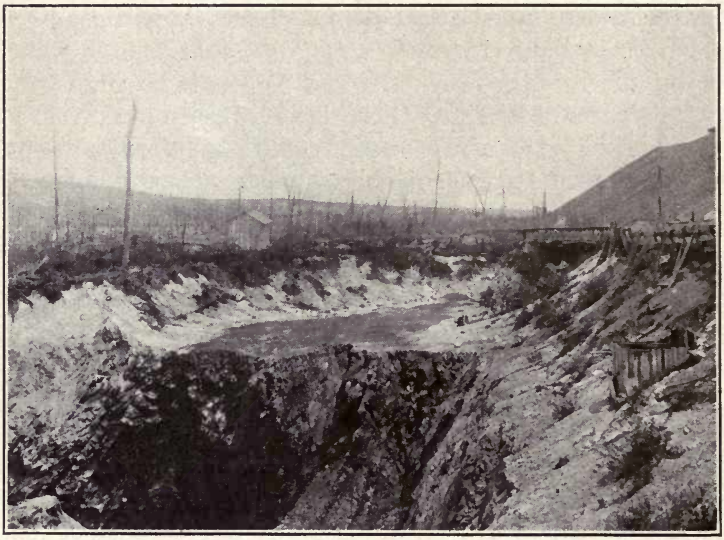

FIG. 22.—Glaciated southern outcrop of mammoth bed, Morea, Schuylkill Co.

Surface, rising slightly from north to south, but generally level over the basin. General appearance as shown in Figure 22, which is looking east along the south outcrop with slight rise in surface to south.

Sandy, pebbly, decayed Pottsville conglomerate drift, light-colored, free from clay, including boulders and masses of conglomerate to 5 feet in diameter. Thickness at section (1), 10 feet; (2), 8 feet; (3), 4½ to 5 feet.

Below this are the following different deposits, each unstratified:

(1). Crushed Anthracite in coarse fragments, solid and of bright luster, 1 foot.

Yellowish-white clay including only small white quartz pebbles from the Pottsville conglomerate. Clay plastic, one-half inch thick.

Solid, highly polished and grooved anthracite, with luster as bright as on a fresh fracture of the same bed 200 feet down the dip.

(2). Crushed Anthracite fragments identical with those in section (1), 18 inches thick.

Mealed Anthracite, dull luster, loose and dry, three-fourths of an inch.

Yellowish-white, clean, plastic sandy clay with no inclusions, 1 inch.

Crushed Anthracite fragments, finer than above, bright luster, one-fourth to three-fourths of an inch.

Mealed Anthracite, dull and pasty, three-fifths of an inch.

Solid, polished, grooved, outcrop of bed, as above.

(3). Red clay, clean and without inclusions, 1 foot.

Reddish, orogenic drift, 4 inches.

Rusty drift mixed with abundant Anthracite flakes, 2 feet.

Partially decayed and softened outcrop of bed, duller than above outcrops.

The lowest layer of the last section is traced for some distance to the south to show the direction of the movement of the ice, and is very well shown in Figure 2 (preface note, F), extending with diminishing color 43 feet across the picture immediately above the horizontally planed bottom sandstone. This tendency of No. 2 to press southward here will be referred to when the end of the lobe is reached against Susquehanna River. The boundary of the Attenuated Border can be drawn through the Pocono opening at Beaver Creek Gap and thence in the red shale (Mauch Chunk) valley of that stream, so as to completely enclose the offset fault in Second Mountain (as Mauch Chunk Mountain is known west of Little Schuylkill Gap), and also this gap. Thence diagonally along Beaver Valley and across Sharp Mountain (as Mount Pisgah is known west of Little Schuylkill Gap) to Cumbola and St. Clair, passing 2 miles north of Pottsville. A more careful study of the Pottsville vicinity may show that a tongue reached that city.

The Strippings. Rates of Anthracite Decay.—Stripping is a method of removing the overlying rock cover of a bed, so that the latter can be entirely removed by the most economical and safe methods. It can be employed only when the surface is valueless and the cost of stripping and mining per ton of the bed is less than in ordinary underground methods. By stripping the cost of timbering, lighting, ventilation and complicated haulage is eliminated, and that of breaking-down, loading and haulage reduced two-thirds. Morea was first worked by the underground method and then stripped. The illustration referred to in the preface note, F, above shows the removal of the cover at the western spoon-end of the basin.

The first impression of a mining engineer who has practiced only in unglaciated regions is the absence of "black dirt" and of decayed and peacock coal at the outcrop of Morea; the next is the absolute soundness of the outcrop of the bed, and the brightness of its luster immediately beneath the clayless and porous drift-sheet. This appears wonderful when it is understood that the ice-sheet which polished this outcrop came into Pennsylvania next after that lobe which left in New Jersey and Pennsylvania the oldest drift in the region, which is called "Jerseyan" and "pre-Kansan." In other words, Anthracite does not decay as fast as its enclosing rocks. The 5 to 15 feet of black earth which outcrops in unglaciated areas and is called "black dirt" represents the decay of the bed since the formation of the Harrisburg peneplain; or better, the remnants of the decay after the sculpturing incident to the atmospheric erosion of the regional valleys into the softer formations.

This removal of the black dirt, the underlying softened lumps surrounded with still softer portions, and the portions of the bed which still showed joint-planes and the iridescent blues and greens thereon which is called "peacock coal," tells the glacialist that such depth of erosion was not accomplished by the edge of a lobe, as stated at the beginning of the discussion of The Pottsville Anticlinal. To properly value the surface and deeper parts of the bed, a series of specimens were taken at Morea and compared with a few at York Farm, in an unglaciated region, and also at Ashland, on the extreme edge of glaciation; but where the ice-sheet had massed against a high ridge, and possessed weight. The following is a description of the samples, and below are the analyses:

1. Morea, sample of the mealed Anthracite, dull and pasty, ⅜ inch thick of section (2) of the drift sheet above. Two samples (a) and (b).
2. York Farm Colliery, sample of the "black dirt" on outcrop, (a) and (b).
3. Morea, north outcrop, sample (a) surface of bench 1, (b) same, 60 feet below surface. Dip of north outcrop 90°.
4. Morea, same, bench 2, (a), surface; (b), 60 feet below.
5. Morea, same, bench 3, (a), surface; (b), 60 feet below.
6. Morea, same, bench 4, (a), surface; (b), 60 feet below.
7. Morea, south outcrop, top bench, (a) surface; (b), 3 inches below; (c), 25 feet below; (d), 38 feet below. Dip of south outcrop 50°.
8. Morea, bottom bench, (a) surface; (b), 18 inches below.
9. Morea, glaciated surface beneath section (1), above.
10. Morea, second section, crushed Anthracite fragments 18 inches thick.
11. Morea, glaciated coal beneath second section, from which the mealed Anthracite paste ⅜ inch thick (analysis No. 1 just above) was scraped.
12. Morea, north outcrop, 250 feet below surface.
13. York Farm Colliery, Salem Bed, lower bench, dip 25°, 20 feet from surface.
14. York Farm Colliery, Tunnel Bed, dip 24°, 80 feet from surface.
15. Ashland, much crushed outcrop, 1 foot from surface.
16. Ashland, same bed, 8 feet from surface.
17. Ashland, same bed, 35 feet from surface.

All of these samples except (14) are from the Mammoth (E) Bed. The highest carbon ratio is 38.37, given by the polished coal taken from under the drift at section (2) above. The paste scraped from above it is mealed Anthracite and not black dirt, as its carbon ratio (11.18) is very little less than the hard coal taken 250 feet below the surface (sample 12), and is far better than the ratio of the solid bottom bench of the south outcrop at the surface (sample 8a, ratio 0.98). These analyses were made by Dr. H. E. Kiefer. Physical tests were made of these samples by Dr. J. Barrell, which show that the decay is preglacial. He reported:

1. "Samples 18 inches from the surface are as strong as those 3 feet from that surface. The strongest of all is but 3½ inches from surface."

2. "Samples near the surface of North Crop are as strong, if not stronger than those at a depth of 55 feet."

3. "Sample No. 3 (No. 12 above) taken 250 feet below surface was an especially hard, solid piece of coal, and gave fairly uniform results; but its average is not different from that of the more fissile samples taken at the North Crop."

"Although enough time has elapsed to give the surface coals (in places) a dull appearance, the strength has not been seriously affected."

ANALYSES OF ANTHRACITE.

In the following analyses the first column represents the combined moisture and volatile parts (I); the second, the fixed carbon (II); the third, the ash, (III); the fourth, the total, (IV); the fifth, the ratio of fixed carbon to ash, (V).

Analyses	I	II	III	IV	V
1a	29.74	64.51	5.77	100.02	11.18
b	30.78	63.35	5.73	100.16	11.05
2a	45.76	29.88	24.36	100.00	1.23
b	44.22	30.99	24.79	100.00	1.23
3a	13.08	82.42	4.50	100.00	18.33
b	4.55	93.02	2.44	100.00	38.20
4a	14.11	77.82	8.07	100.00	9.64
b	5.30	88.62	6.08	100.00	14.65
5a	15.66	67.17	17.17	100.00	3.91
b	4.12	86.76	7.12	100.00	12.19
6a	13.01	83.97	3.02	100.00	27.75
b	5.20	90.28	4.52	100.00	19.99
7a	8.41	88.39	3.20	100.00	27.70
b	7.49	89.87	2.64	100.00	34.07
c	7.34	87.19	5.47	100.00	15.95
d	6.12	89.90	3.98	100.00	22.59
8a	36.73	31.38	31.90	100.00	0.98
b	11.13	84.97	3.90	100.00	21.77
9	19.45	77.60	2.95	100.00	23.45
10	31.34	59.48	9.18	100.00	6.48
11	14.17	83.65	2.18	100.00	38.37
12	4.97	88.21	6.82	100.00	12.93
13	8.91	88.69	2.40	100.00	37.03
14	9.60	79.41	11.00	100.00	7.22
15	....	....	....	....	3.51
16	....	....	....	....	8.65
17	....	....	....	....	12.58

The Western Middle Basin.—Its eastern rim is 5 miles northeast of Morea, and, therefore, completely covered by No. 2. Morea is on the edge of its high southern rim of Pottsville conglomerate overlooking Mahanoy Basin. Wetherill Junction, 4½ miles southwest of Morea, has an elevation of 1200 feet above ocean level, and is thus 300 feet below

Morea. It is in the gap in Broad Mountain through which the headwaters of Schuylkill River flow from the swamp immediately south of Morea. The crest of Broad Mountain rises to 1800, and is thus 300 feet above Morea and 600 above Wetherill Junction. The boundary of the Attenuated Border has been drawn to St. Clair, 2 miles farther south, though it is probable that the boundary covered Pottsville. The surficial mantle at Port Carbon must be studied where it is not masked by culm.

The crest of Broad Mountain was covered by No. 2 at the headwaters of Silver Brook, 3 miles southeast of Morea. Its crest west of the gap at Wetherill Junction (1800) is 1½ miles nearer Morea than is St. Clair, and but 300 feet above it. It is probable that the ice-tongue, that was thrust down towards Pottsville through Broad Mountain Gap, massed its western margin high up on the flank of the mountain, if it did not reach its crest; as the great weight of the ice at Morea indicates a thickness sufficient to overtop the mountain by more than the 300 feet necessary to cross, plus the drop of 50 feet per mile for the distance between. The resultant of the regional trend westward to Susquehanna River and that southward as shown by the movement of the coal flakes in the drift would pass through the crest of Broad Mountain west of the above gap, and thus it will be necessary for a careful study of its crest to be extended westward from the border of the red shale valley on its northern flank, opposite Frackville, where, at a higher elevation than the crest of the Pottsville ridge forming the southern high border of Mahanoy Basin, we find Pottsville conglomerate boulders in Pottsville drift as at Morea but on red shale, showing the bending of the edge of the ice-tongue about the gap, which is 1 mile broad at the 1500-foot contour.

Mahanoy Basin.—Outside of the Pottsville inner rim of this basin is the anticlinal valley (Mauch Chunk) of Mahanoy Creek which forks at Barry on account of the complete erosion of the formation: the left of the swallow-tail reaching Susquehanna River at Millersburgh; the right reaching the same where Line and Little mountains join about the spoon-end of the formation, 15 miles farther north. Mahanoy Creek flows in an almost straight line along this northern fork for 30 miles between Frackville and the gap in Line Mountain where it escapes southwestward to join Susquehanna River at Herndon. This red shale valley from its end at Frackville to the gap at Locust Dale is worthy of careful study, both to find whether Broad Mountain crest was reached, and whether the ice-sheet did more than place its southern margin astride the Pottsville rim of Mahanoy Basin as far west as the gap at Locust Dale. The entire Mahanoy Basin was covered by ice, as shown by numerous sections in drift, and at Frackville that margin extended 2½ miles south of its Pottsville border. The eastern end of Mahanoy Creek Valley is plainly covered by a drift-sheet. The ice moved along the strike of the formations, and the sheet soon approximates to the local outcrop. There was no opportunity for an examination of sections to the rock floor, and there is a deep surface wash. No erratics were seen between Gordon and Barry where the swallow-tail forking occurs, and west of Barry the red shale outcrops without a cap.

Ashland Basin.—That the margin of the ice moved astride of the Pottsville rim from Frackville is shown by three things: the smoothing of the crest; the crag-and-tail drift formation at its end at Ashland Gap, and the complete crushing of the coal beds, as described in the comparison of coals above. This is checked by evidences of an ice-tongue thrust through Ashland Gap. There is a slight red shale (Mauch Chunk) ridge immediately south of and against the Pottsville one, with a slight trough between, and with a gap in it east of Ashland Gap. Through this red shale gap a stream of Pottsville boulders and cobbles was poured upon the red shale plain for a short distance. The ice-margin was thus outside of the Pottsville ridge at Ashland Gap, as well as 2½ miles outside of it at Frackville. The boundary of the Attenuated Border can be drawn from St. Clair so as to pass high up on the northern flank of Broad Mountain, and thence across Mahanoy Creek Valley to the Big Run Gap in Mahanoy (Pottsville) Mountain at Locust Dale. This place is 1¼ miles south of the crest of Locust Mountain (1758) and 1000 feet above ocean level. Big Run drains the wedge-end of Ashland Basin, which extends 9 miles west of that place. The ice-sheet passed up Big Run and ponded its water. There is thus an abundance of drift in this wedge-end, as will be seen below. Ashland Basin was entirely covered by the ice.

Locust Mountain.—This anticlinal Pottsville ridge passes southwest from North Mahanoy Mountain to Mahanoy Mountain, joining the latter at 1800 feet above ocean level and separating the Ashland and Shamokin Basins. Mr. J. P. Lesley (Letter of transmission, vol. Z, p. xli, 2d. Geol. Surv. Pa.) tells of Professor Edouard Desor (1811–1882), the Swiss glacialist, and himself finding glacial marks on the crest of Locust Mountain in the summer of 1851. This overtops Mahanoy Mountain at Big Run Gap by 250 feet and is but 1½ miles north of it. To cross this crest (Locust Mountain) there must have been 300 feet of ice on it, which proves the covering of the Ashland wedge-end. The railroad from Locust Dale passes up Big Run Valley to Locust Summit. From this place to Locust Gap, in Locust Mountain, is a continuous cutting in drift. It is one of the finest exhibitions in Pennsylvania along the Attenuated Border. There is, however, no "attenuation" here, as the drift is the usual sandy clayless body including abundant various sandstones and conglomerate masses. The exposure just east of Locust Summit is especially fine. From Locust Summit (1340) to Locust Gap is a fall along a ponded and filled valley draining northward into Shamokin Creek, and cuttings in a thick drift-sheet are numerous. It carries large boulders and rests of a glaciated rock floor.

Shamokin Basin.—The outer (Pocono) border of this is Little Mountain, which is an extension of Nescopeck Mountain, which, in turn, extends the Moosic-Pocono barrier across the ridge at Bear Creek Summit (2000) and sweeps S. 50° W. for 36 miles to Susquehanna River as the gradually rising border of the Mauch Chunk valley of Nescopeck Creek, and, beyond the saddle therein, of Scotch Creek. At the Nescopeck Creek Gap it rises 900 feet above that stream. At the Susquehanna, near Catawissa it turns sharply S. 45° E. for 9 miles as Catawissa Mountain till north of Raven Run it returns to its former trend by a short curve, and as Little Mountain reaches Susquehanna River. Its average elevation as Nescopeck Mountain is 1750 (2000-1600); as Little Mountain, 1300, but where it unites with Line Mountain (average 1300) there is a knob at 1500, rising 1100 feet in one-half mile from the Susquehanna River bank. This Pocono barrier separated lobes 2 and 6. The sudden bend at Catawissa, however, enabled No. 6 to move directly southward, and to cross Little Mountain along its whole length from north of Raven Run to Susquehanna River, as shown by the drift-sheet in the red shale (Mauch Chunk) valley between it and the inner (Pottsville) rim of Big Mountain. East of Shamokin Gap this sheet is at least 30 feet thick, as shown by wells sunk into it. Whether No. 6 crossed Big Mountain is not known. The evidences of ponding in the valley between Locust Summit and Locust Gap, noted above, could have been produced by the presence of No. 6 in the red shale valley at Shamokin Gap, as Shamokin Creek would have been dammed and the water backed to its source so as to include the above valley, and it would not be necessary for No. 6 to have crossed Big Mountain.

The evidences of ponding are greater north of Locust Gap, as there is a swamp extending northeastward to Mount Carmel in which Shamokin Creek rises. The evidences of glaciation below the level of ponding, which have not been ascertained, must of necessity be confused, if not submerged by the water-laid drift. At Excelsior, 3 miles west of Locust Gap, the railroad cutting shows the rock floor planed and covered by drift. The valley is narrow here and obscured by culm. Greenbank is 2½ miles west of Excelsior, and directly north of the junction of Locust and Mahanoy mountains at an elevation of 1800 feet above ocean level. One mile east of Greenbank there is another exposure of drift on a glaciated rock floor. There are two sorts of drift in the flood-plain, the upper is stratified. Unstratified drift is found 55 feet above and south of Shamokin Creek in Shamokin, as shown in Figure 23. There is no southward movement of the ice shown by coal flakes, and thus the sheet seems to have been that of No. 2. Outside of Shamokin Gap in Big (Pottsville) Mountain, and on top of the saddle in the Mauch Chunk valley south of Trevorton, Figure 24 shows the crossing of Little Mountain (in the background) by No. 6 which carried the Pocono boulders

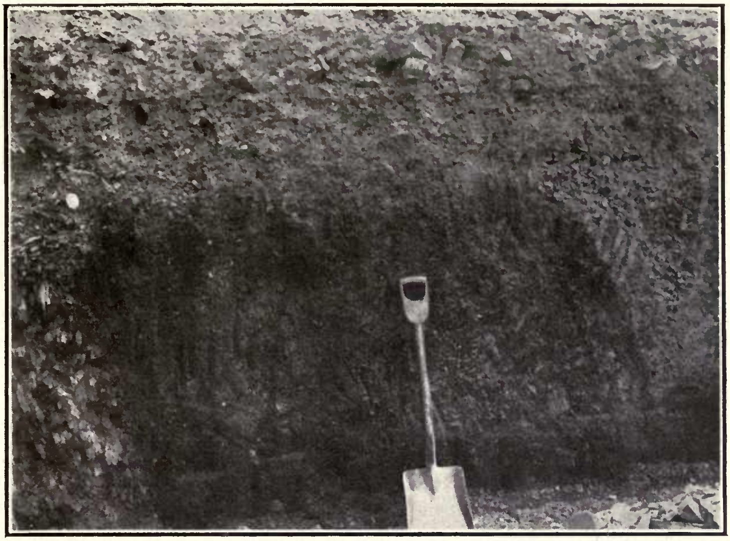

Fig. 23.—Glaciated coal outcrop and drift cap, Shamokin, Northumberland Co.

Fig. 24.—Pocono cobbles and trash carried from Little Mountain (background) across Mauch Chunk valley at Trevorton and left on Pottsville, Northumberland Co.

plentifully scattered over the surface, and found in the drift, from the mountain crest across the valley and up the northern flank of Big

Mountain where the camera was placed. This proves the crossing of Little Mountain and the ability of the ice-sheet to mass against Big Mountain. Whether it crossed the latter is doubtful, as it averaged 200 feet higher than Little Mountain. Where it met Mahanoy Mountain at the spoon-end of Shamokin Basin there was a corresponding knob 200 feet higher, and rising to 1700 feet above ocean level. The western end of this basin must be examined carefully. Immediately below this knob, at Hunter, on the Mauch Chunk valley is a drift-sheet carrying the same dense, white Pocono boulders. Across the valley to the southern margin is a sandy yellowish drift with infrequent Pocono boulders. As there was no glacial dam here, this is land-laid drift, and evidently from No. 6. The high Pocono rim about this Mauch Chunk valley of Zerbey Run (Trevorton to Dornsife) was therefore covered by the eastern margin of No. 6, and there was thus a meeting with No. 2 at the end of this region, if not farther east in the Shamokin Basin. Referring again to the tendency of No. 2 to gain southing at Broad Mountain and Ashland gaps, it seems as if No. 6 may have pushed No. 2 southward by crossing the Pocono crest of Nescopeck-Catawissa-Little Mountain, and by this have increased its power so as to cross Locust Mountain and move southward through the above gaps. The boundary of the Attenuated Border is drawn through Big Run Gap at Locust Dale so as to include the wedge-end of Ashland Basin, thence over Locust Mountain about the basin of the western branch of Shamokin Creek, through the high gap in Big Mountain at Trevorton, thence along the flank of the latter mountain and at the base of its high knob across the valley of Mahanoy Creek to the Pocono barrier of Line Mountain, where it sweeps about it several hundred feet above the valley floor, and passes over Little Mountain east of the knob, and thus into the main valley of Susquehanna River. The ability to cross Little Mountain indicates a thickness of ice sufficient to place the glacial surface at Sunbury 2100 feet above ocean level.

CHAPTER VII

SUSQUEHANNA DRIFT. LOBE NO. 6

The St. Lawrence-Black River-Susquehanna lobe crossed the Black River saddle, the Mohawk trough and the Pennsylvania plateau east of Moosic Mountain, which separated it from No. 2 and probably kept it from crossing into the Lackawanna Anthracite Basin, as the Pocono ridge from Moosic Mountain southward to the gap at Pittston averaged over 2000 feet above ocean level, and beyond that gap was but 1000 feet above it. No. 6 crossed into the Wyoming Valley here and moved south so as to rest against Nescopeck Mountain and extend westward to the highlands (2300) on the boundary between Wyoming and Sullivan counties. The trend of the lobe was about S. 30° W. here, and thus 30° nearer south than No. 2, with an increasing pressure against Nescopeck Mountain, which enabled it to cross it, as will be seen, and to pass south far enough to cross Little Mountain as described immediately above. It extended at least to the broad saddle at McClure between the Middle Creek and Juniata basins, and at the left a tongue was compressed between Shade and Jacks mountains (both Oneida ridges), while the right margin moved along and against the Oneida zig-zag between White Deer and Paddy mountains, after coalescence with the left margin of No. 7.

The outcrops crossed extend from the Chemung to the coal until past the Wyoming Valley. Thence to the McClure saddle they are between the Oneida and the Pocono. This brings to the mixture the Lewistown limestone and Salina shale, which distinguish this from the drift of No. 2. The movement with the Susquehanna River furnished an abundance of rolled gravel, which in places is carried over the highest ridges. Much of the valley drift is the overwash from the great moraine, which crosses the river at Beachhaven, 42 miles north of Little Mountain Knob. The area covered by No. 6 is thus divided:

The North Branch.
The Main Valley.
Middle Creek Valley.
Jacks Mountain and Penns Creek.

The North Branch.—The Berwick gravels have been described (see preface note, D, p. 180) as an unstratified clayey drift with rolled stones where granite and anthracite meet, a stratified overwash, and a cap of unstratified sand with iceberg inclusions. Figure 25 shows Susquehanna gravel carried over Nescopeck Mountain and mixed with rolled Pocono from its crest and angular Mauch Chunk from Scotch Valley. The mixture is on the slight ridge of the latter formation that forms a continuation of McCauleys Mountain at Mountain Grove (1010 above ocean level). This is south of the trough of Scotch Valley, 2 miles south of the crest of Nescopeck Mountain, and 6½ south of Beachhaven where the great moraine crosses the north Branch of Susquehanna River. It is also directly north of Frackville, and shows that a pressure southward was exerted on No. 2 here also. It is thus probable that No. 6 may have coalesced with No. 2 over the last 36 miles of its path.

The crossing of Little Mountain by No. 6 has been noted above. The dropping of Susquehanna gravels behind ridge crests has been mentioned in chapter four, in the fifth cause for the approximation of drift to the local outcrop. Figures 26, 27 and 28 illustrate the passage of No. 6 from Susquehanna River to Little Mountain when once past the Nescopeck barrier. The first shows the abundant rolled pieces south of the hill-crest 2 miles south of the river and 300 feet above it. The second the scanty gravel on the hill-crest 6 miles south of the same, and just

FIG. 25.—Pocono drift from Nescopeck Mountain on Mauch Chunk extension of McCauleys Mountain, at Mountain Grove, Luzerne Co.

FIG. 26.—Pocono and Pottsville conglomerate on Catskill at hill-top north of Rushtown, Northumberland Co. (Gravels from Susquehanna River.)

north of and 225 feet above Shamokin Creek. The large cobble is rolled and glaciated Pocono. The third is on the same road as the other two, south of Shamokin Creek and on a Hamilton ridge-crest. The Susquehanna gravels have disappeared and the semi-rolled pieces are from

FIG. 27.—Pocono cobbles on Hamilton on ridge north of Shamokin Creek at Deiblers, Northumberland Co. (Showing disappearance of Susquehanna gravels.)

FIG. 28.—Gravels from Shamokin Creek on ridge-top near cross-road to Paxinos, south side of ridge, Northumberland Co.

Shamokin Creek bottom, 190 feet (vertical) below and 1½ miles to the north.

The Main Valley.—The river gravels thus carried by No. 6 are abundant at 800 feet above Susquehanna River east of Sunbury, but die out and are replaced by local sorts east of Selins Grove. At low levels an overwash underlies sandy clay like that at Berwick. The boundary of the Attenuated Border is marked across Susquehanna River by 16 islands, on two of which the Lewistown Branch of Penna. R. R. crosses at Selins Grove. A large part of the overwash came down Penns Creek, and is Oneida, which rock is not found along the North Branch of the river. Near the railroad crossing the river flows on a rock floor of Salina.

Little Mountain Narrows.—The knob where Line and Little mountains meet rises to 1500, or 1100 feet above the Susquehanna bank ½ mile to the east. The river is about 1 mile broad between banks at the junction of the north and west branches. At the narrows it is 3400 feet between banks, and Hoover's Island occupies 1200 feet. At the 700-foot contour the breadth is 1½ miles. This is 300 feet above the water, and the valley above the narrows at this elevation is 30 miles broad at Sunbury, and 15 across the wedge-ends of Shade and Jacks mountains. The saddle at McClure, in Middle Creek Valley, is at 640 above ocean level. The drainage of 13,000 square miles of Pennsylvania, plus all of New York west of Delaware water-shed which could not escape westward, all of Canada under the same conditions, all of the ablation of the main trunk forced through the Susquehanna affluents or over the plateau, and all of the ablation of No. 6 and the northern half of No. 2, passed through these narrows. The berg-inclusions in the Berwick upper sands, and in the terrace north of Rupert narrows, 160 feet above the river, point to extensive clogging by bergs there. Similar clogging at the narrows under consideration laid the similar cap along Penns and Middle Creek valleys, beneath which we find drift. This is not above 640. The drift on the hill near Sunbury, 800 feet above the river is thus land-laid, also the still higher drift 1000 feet above the same, where No. 6 passed to cross Little Mountain.

Middle Creek Valley.—The debouchment is curious, being through a gorge 140 feet broad at stream level, and less than 1000 feet broad 75 feet above it. There is sudden broadening above the gorge to 1800 feet at stream level, and to 3200 feet at the 1000-foot contour. The Susquehanna flood-plain runs for 10 miles up the valley with but slight rise. From the McClure saddle where the stream rises, to within 8 miles of its mouth, the valley is 6 miles broad, and is bordered by Oneida ridges, Jacks Mountain (1540) on the north with crest 900 feet above its trough and Shade Mountain rising similarly on the south. A slight Clinton ridge lies next to and apart from Jacks Mountain. The valley floor is Salina and Hamilton. The Lewistown Branch of Penna. R. R. passes through a great many cuttings in drift beneath a sandy cap. The drift is continuous to Adamsburg, changing from gravel to angular pieces east of the latter station. Between this place and Troxelville, however, the Middle Creek bottom (Hamilton) shows abundant rolled pieces as shown in Figure 29. These are not the Susquehanna gravels carried west of Beaverton, and the rolling is too great to have been formed in so flat a stream within less than six miles of its source. Besides the stream filling is deep.

There is a surface wash between the McClure saddle and Juniata River at Lewistown, which masks whatever is beneath. There is a cutting on the saddle of considerable depth into sandy clay including small stones. This extends through the town. At Raub's Mills, between Adamsburg and the saddle the stones are larger, and there may be a

FIG. 29.—Bed of Middle Creek between Adamsburg and Troxelville, Synder Co. Drift of Oneida to Salina on Hamilton.

slight moraine. There is also a slight gravel ridge running from the northern end of Shade Mountain across the valley. The boundary of the Attenuated Border is drawn from the end of Little Mountain so as to enclose Freemont on the headwaters of Mahantango Creek, thence around the northern end of Shade Mountain and along its western flank to McClure, where it curves across the valley to the eastern flank of Jacks Mountain west of Troxelville, where Oneida boulders have been carried across the Clinton valley, over the Clinton ridge of Gold Hill and left on a Salina valley.

Jacks Mountain and Penns Creek.—Troxelville is 630; Jacks Mountain crest on the road thence to Glen Iron (Millmont), 1540. It is an Oneida anticlinal, steeper on the north side, and with a sandy cap near the crest. This is absent from the south side. A brook rises near the crest and flows down the north side over local pieces till within 143 feet of the valley where it is full of gravel from Penns Creek, and this is carried down to the plain. The ice-sheet massed against this steep flank, developed a shear and sent the clear ice and sand over the ridge. This calls for a thickness of 1000 feet over Penns Creek, and thus agrees with the 2100 feet of surface elevation at Sunbury mentioned at the end of chapter six. The place where the boundary of the Attenuated Border crossed this Mountain is not known, as the wilderness is unbroken, and no opportunities were found for search westward. It must have been, however, west of this road between Troxelville and Glen Iron.

Penns Creek.—This has a delta 1 mile broad, and the Susquehanna flood-plain runs up its valley for 20 miles with but slight rise. The valley was covered by No. 6 from the mouth to its gap through Paddy Mountain, which is one of the Oneida zig-zags of the border between the Susquehanna Valley and the many trough and canoe-shaped valleys with Oneida walls, Martinsburg rims and Cambro-Ordovician floors which lie parallel to one another south of Bald Eagle Mountain. This zig-zag also separated No. 6 from No. 7.

At Millmont well-sections gave a freshly scoured rock floor with 2 feet of quicksand upon it, covered, in order, by 6 feet of assorted stony gravel free from sand, 2 feet of sand, and 15 feet of sandy silt. The average well depth is 25 feet. From Glen Iron station westward the railroad cuttings are in red silt including glaciated cobbles and boulders, angular masses and slabs of local rock—some of the rolled pieces are of good size. These show on the surface also all the way westward to Paddy Mountain Gap, where we pass out of the area covered by No. 6. The boundary of the Attenuated Border lies along the northern flank of Jacks Mountain and into the wedge-end where it returns as Paddy Mountain, so as to include Panther Run Valley.

CHAPTER VIII

PLATEAU DRIFT. LOBE NO. 7

The Ontario-Finger Lake-Allegheny Plateau lobe crossed the Erigan Valley in the meridian with its center-line passing through the Cayuga-Seneca-Lakes pocket and the channel of Susquehanna River, following the latter after it crossed the Pennsylvania boundary for 12 miles and then spread fan-wise; the left margin passing across the highlands about Grant's Lake (2200-2400) parallel to the Wyoming-Sullivan counties boundary (about S. 16° W.) and coalescent with the right margin of No. 6. The right margin of No. 7 was caught in the broad and shallow troughs of the plateau and turned so as to move along them between S. 70°–80° W. With the first portion passed the water forced over the plateau which could not escape southward through the Susquehanna trough, as it turned eastward to cross the plateau crest at Tunkhannock, but followed the ice and swept the plateau clean, so that where the great moraine is supposed to cross the trench of Lycoming Creek there is no vestage of it, or for some distance east or west. The rocks that can be expected in the drift of this lobe will not vary, between the Pennsylvania boundary and West Branch of Susquehanna River, from those of No. 6 north of the Wyoming Basin. In the valley of this West Branch the rocks down to the Clinton are met with, and south of Bald Eagle Mountain they extend down to the Cambro-Ordovician limestone; but the drift there is mainly from the Oneida and Medina ridges—both rocks much softer and more porous than those on the Kittatinny crest. The Plateau crests are mainly Pennsylvanian remnants with Pottsville as the rest of the surface, Mauch Chunk outcropping thinly along the walls of river trenches and Pocono as their rock floors 1000 feet below the plateau level. The valleys south of Bald Eagle Mountain have, with one exception, limestone floors, thin Martinsburg borders and high Oneida rims; the exception is an anticlinal valley in Clinton. The drift of the left margin thus extends from the Cambro-Ordovician limestone to the coal; of the right, is confined between the Pottsville and the coal. The area covered by No. 7 is thus divided:

Penns Valley to Nittany Valley.
Sunbury to Keating.
Sinnemahoning Creek.
Glacial Lake Lesley.

Penns Valley to Nittany Valley.—The former is the region where Penns Creek rises and forms the continuation of the Attenuated Border beyond Jacks Mountain and Panther Run Valley; the latter is the largest and most western of the canoe-shaped valleys south of Bald Eagle Mountain and west of the zig-zags between Paddy and White Deer Mountains—these zig-zags being of Oneida-Medina ridges that surround six valleys east of Nittany Valley. Penns is swallow-tailed at the ends; the next north, Brush and Sugar, are canoe-shaped; still farther north are three hopper-shaped ones immediately south of Bald Eagle Mountain; the two largest—Nippenose and Mosquito—having limestone floors. One is trenched into a Clinton anticlinal, and one only to the Martinsburg. Two-thirds of the area is Oneida-Medina, and the drift is sand and cobbles from this ridge-former, is lighter over the uplands but has the usual red where the limestone or Martinsburg outcrop.

Drift ends in Penns Valley at Spring Mills, is absent over the limestone roll to Center Hall, State College and Bellefonte. The east end of Brush Valley and all of Sugar and the more northern valleys were completely covered by ice. The boundary is drawn over Paddy Mountain to Poe's Mills, Coburn, Spring Mills, Elk Creek Gap, Madisonburg (Brush Valley), thence over the Oneida rim to include the western end of Sugar Valley and pass over Big Mountain south of Big Fishing Creek Gap, if not south of the more southern one, as that has an overload delta west of its gap into Nittany Valley. The boundary should include Hecla Furnace. Across Nittany Valley the drift is hidden by *Lesley* sands, and cuttings are not numerous. It is found beneath the above sands at Huston, Figure 30. This valley demands considerable study, as there are many overload fan-cones where glacial streams discharged into Lake Lesley.

Sunbury to Keating.—The striæ at the head of Little Muncy Creek bear S. 5° W. and show the trend of the border line between Nos. 6 and 7.

Fig. 30.—Red silt including Oneida and Martinsburg on Cambro-Ordovician limestone, north of Huston, Nittany Valley, Center Co.

The valley of the North Branch of Susquehanna River is deeply filled between Sunbury and Lock Haven, and thence to Vail in Bald Eagle Valley, so that the ridges and slight elevations rise abruptly like islands from the level *Lesley* sands and clays. The presence of the ice-sheet south of Bald Eagle Mountain proves that this ridge, rising 1400 feet above the filled valley was crossed by it. This indicates a glacial surface rising to 2100 feet, which is the elevation calculated for Sunbury in order to cross Jacks Mountain by No. 6. Direct proof is found in the drift sheet of local material on the eroded anticlinal that forms the northern flank of White Deer Mountain, directly south of Williamsport, at 1180 feet above ocean level, where a rolled Medina cobble and white quartz pebble were found after passing over Bald Eagle Mountain, across the intervening valley and 600 feet upwards on the northern flank of White Deer Mountain, Figure 31. This thickness is not excessive for the ice-sheet, as the line of the great moraine is but 7 miles north of the place where these rolled pieces were found; but, with the average slope of No. 6—as this portion of No. 7, on the margin between the two, should follow that slope—the glacial front should be 39 miles south of Williamsport, if that front rested on a surface 900 feet above ocean level. Spring Mills, where the rolled drift on the limestone floor ended, is 40 miles S. 45° W.

Lock Haven.—The filled valley turns here and extends up that of Bald Eagle Creek to the Dix saddle and the Juniata discharge of Lake Lesley. Alleghany Mountain forms the western border of this valley, and, deeply trenched into its Pennsylvanian-Mississippian measures, the West

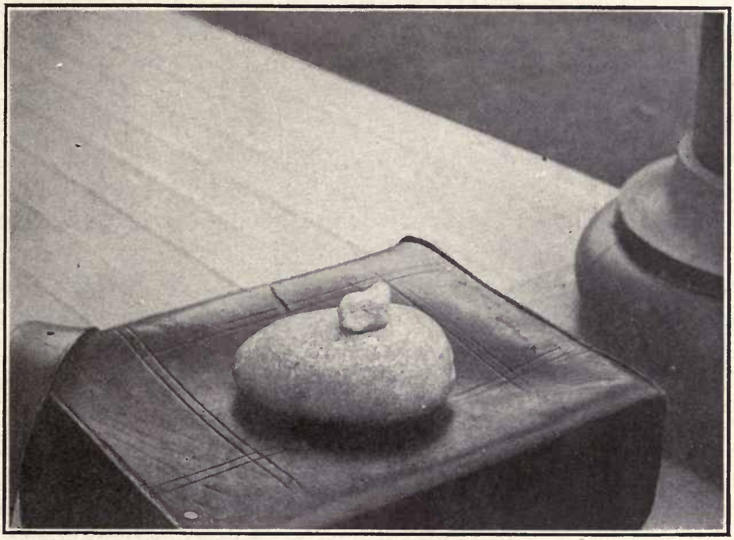

FIG. 31.—Medina cobble and quartz pebble from drift on White Deer Mountain, south of Williamsport, Lycoming Co.

Branch of Susquehanna River comes from the northwest. In that direction the surface is Pottsville and the coal forms the crests: the very thin Mauch Chunk outcrops half way down the vertical walls of the trenches in which the rivers run: the Pocono forms the remainder of the trench-walls and the rock floor. Six miles north of Lock Haven and over 700 feet above it (1500), where the glacier certainly passed, large boulders of sandstone are arranged in trains, and in many cases are forced into the putty-like clay even with the surface. These are 4 feet in diameter at times. The clay includes flakes of sandstone, slabby blocks of the same, flakes of red and other shales of lighter (yellow) color. At this elevation the ice-front should be at least 10 miles to the south, and thus 4 south of Lock Haven.

The West Branch.—Rattlesnake Run rises 4 miles north of the river and above Lake Lesley (1110). Its polished rock floor is crossed by a moraine of rolled drift of all sizes that did not come up-hill from the Susquehanna, and could not have been thus thoroughly rolled in the short distance from the source. This brings the ice past Haneyville, 20 miles southwest of the great moraine. Several runs from the south, between Hyners and Westport, show rolled drift in their beds, and thus point to ice south of the river. *Kettle Creek* rises near the great moraine at Germania. Its flood-plain shows gravel, but its bottom is slabby. The West Branch at Keating comes from the Clearfield region to meet Sinnemahoning Creek which drains the southern side of the Pennsylvania plateau. The former shows signs of drift, so that the Attenuated Border is drawn from the point south of Mill Hall Gap in Bald Eagle Mountain so as to pass south of this main stream to Keating.

Sinnemahoning Creek.—This flows in a trench parallel to, 30 miles distant from and 1200 feet below the great moraine. Bars and terraces occur wherever slack water obtained. There is no regular filling and their tops vary spasmodically between 15 and 120 feet above the stream, jumping within a few miles as follows: 80, 100, 15, 14, 40, 80, 120. The East Branch rises 3 miles from Coudersport and south of the Allegheny watershed, in a valley where 18 feet of land-laid drift are covered by a wash. The flood-plain shows drift, but the stream-bottom is slabby. The surface of the plateau about the trench on either side is an impassable wilderness from which the coal and lumber has been removed and a tangled underbrush covers everything. There are few roads and the trench walls are sometimes 900 feet high. There was no survey of the surface.

Bennets Branch.—This rises against the Allegheny watershed at 1678, flows east and joins the Sinnemahoning at Driftwood. This place is below the water level of Lake Lesley (1110-1130). For 20 miles westward—to Medix—the Pennsylvania Railroad passes through cuttings in rolled drift from 100 to 1300 feet long, and rising from 8 to 20 feet above the track. This might be thought to be due to the ponding of Lake Lesley, were it not that Medix is above its level. The discovery by Mr. Barrell that Bennets Branch reversed its current during glacial times indicated that the ice-sheet crossed Sinnemahoning Creek at Driftwood. The indications of reversal are the prevalence of the lower parts of the affluents of the stream to turn against the present current. Johnson's Run, from the south, shows the presence of the ice-sheet over its old down-stream mouth, which is filled with drift, until a new channel was trenched through the rock on a bend up stream.

There is a long cutting immediately east of Medix in a variety of drift. The south side of the same has a face 30 feet high. From its top the same gravel can be carried along the surface in an upward curve between 1200-1500 feet where it reaches the mountain flank. There were excavations sunk in places to test theformation below track level. At this level it is a decided land-laid drift composed of the old surficial mantle mixed with insufficient vegetable material to completely reduce the ferric salts. Its base is a bluish-brown clay including rolled and sub-angular boulders. Above this is an unstratified body of local flakes with larger fragments, waterworn and subangular. West of the center are boulders up to 3 feet in diameter. At the western end this changes to a stratified gravel. The whole is a moraine showing the evidences of deforestation, of ponding and of an overwash. This extends to the south as shown by the presence of the boulders and angular fragments in the bed of Medix Run. One mile west of Medix station is a cutting through another and entirely different formation, 700 feet long, angular and slabby, without rolled pieces of any sort. This is the moraine of farthest extension; the other is one of retreat. There is no gravel west of this last, but there are two terraces in a broad and filled valley: at Weedville, 5 and 12 feet; at Penfield, Tyler and Winterburn, 3 and 5 feet. The flood-plain is composed of flakes of Mauch Chunk. This indicates a quiet reversal. It is not known whether the discharge was into Red Bank Creek or Clarion River. The former shows faint indications of abnormal flooding; the latter shows a deeply trenched and broad channel into the rock floor with a gravel filling, but this could have been made by agencies considered later.

Portage Branch.—This rises on the summit of the Pennsylvania plateau and is joined by West Creek at Emporium. Its office as a discharge of Glacial Lake Wright will be described in chapter ten. It was crossed by the ice-sheet, as shown by ponded drift at Shippen, 6 miles below the summit. The great elevation above Lake Lesley is evidence that the ponding of water must have been caused by a local obstruction.

West Creek.—This stream was also closed so as to raise the water level several hundred feet above that of Lake Lesley. The ice-sheet came to Emporium to accomplish this. The rock floor of this stream has been trenched so that the affluents come in at so much higher an elevation that they seem to leap into the valley. At Beechwood (1240-1260) is a symmetrical delta through which the stream has cut a channel on the up-stream side (as reported by Mr. Barrell). This indicates a reversal of current and flow over the West Creek Summit (1696) into Elk Creek, a tributary of Clarion River. With the exception of an occasional boulder in the mixture the rocks are local and angular. In the adjoining streams the discoidal gravel carries boulders. The deposits are either drift, or the boulders are berg-carried. There are no deltas as high as Rathbun (1317). West Creek flows on a rock floor, but there is gravel in the flood-plain too well rolled for a carriage of 5 miles from the source. The hillside cuttings show ordinary wash, as in the Allegheny region. At the summit is a 15-foot cutting in silt including boulders. This is 6 miles north of Medix.

Glacial Lake Lesley.—This has been described in preface note, D and F. The elevation of the ponded water was probably 1130. The col at

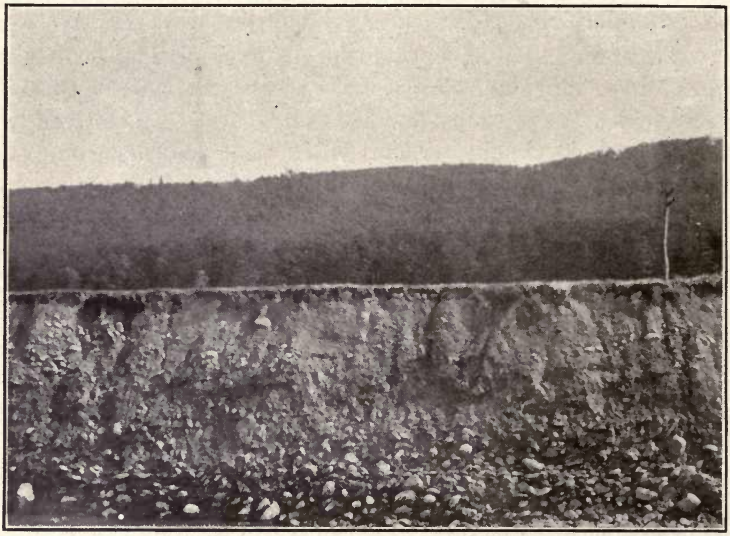

FIG. 32.—Outwash from Lake Lesley, showing gradual slackening of current, one-quarter mile south of Vail, Blair Co.

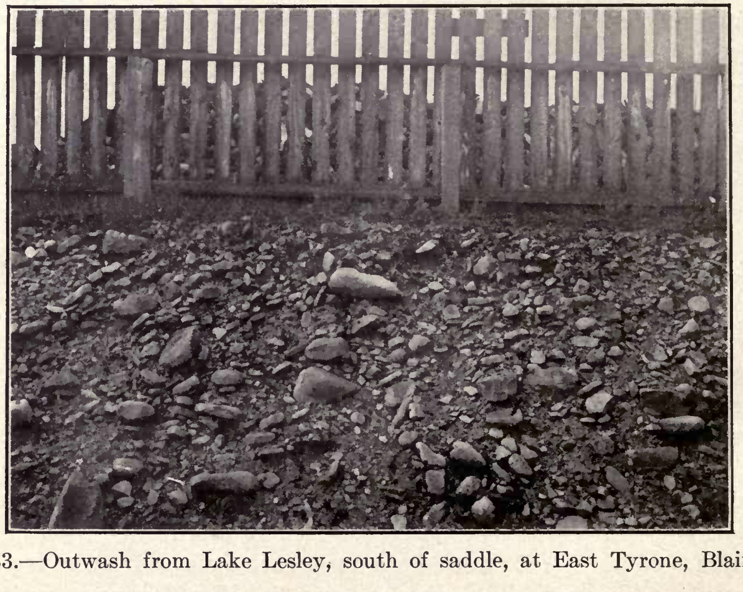

FIG. 33.—Outwash from Lake Lesley, south of saddle, at East Tyrone, Blair Co.

Dix is now about 1110, but by the steeper slope on the Juniata side the watershed has been pushed north. Figure 32 shows the sequence of deposits and slackening of the flow over the col a short distance south of

Vail. The iceberg inclusions are seen in the clay cap. Figure 33 shows the overwash near the bottom of the southern slope, and about 50 feet above Little Juniata River at East Tyrone.

The large sausage-shaped fan-cones opposite the gaps in Bald Eagle Mountain which project across the valley so that the North Branch of Susquehanna River is forced to make great loops a mile or more to the north, and off the Lewistown limestone floor, in order to pass around them, have been noted in both papers referred to in the above preface note. The one to the east curves with the present drainage: the others against it, and with the reversed flow by which Lake Lesley discharged the drainage of 5400 square miles over the col at Dix into Juniata River. The material carried therewith is shown along that river, and a very

Fig. 34.—End of fan-cone from Antis Gap, near Jersey Shore, Lycoming Co.

small part of it remains in the two islands at the mouth of the stream in Susquehanna River—one of them being 2 miles long, and the largest in Pennsylvania.

The Jersey Shore fan-cone was originally more than 2 miles long. Part of it is now an island in the river, 2 miles long and ½ mile broad. This length was the original breadth of the fan-cone, whose remnant now is more than 1 mile long, ¼ mile broad, and 150-170 feet above the flood-plain. Figure 34 shows its end, Figure 35 its structure. The material is the limestone and Mărtinsburg slate including light-colored Oneida and Medina cobbles.

Figure 36 shows a section on the south side of Mill Hall Gap in Bald Eagle Mountain. At the bottom is land-laid drift covered by the sandy clay of Lake Lesley. Figure 37 is a cutting in the fan-cone outside this gap, which also turns up the valley with the reversed flow. Returning

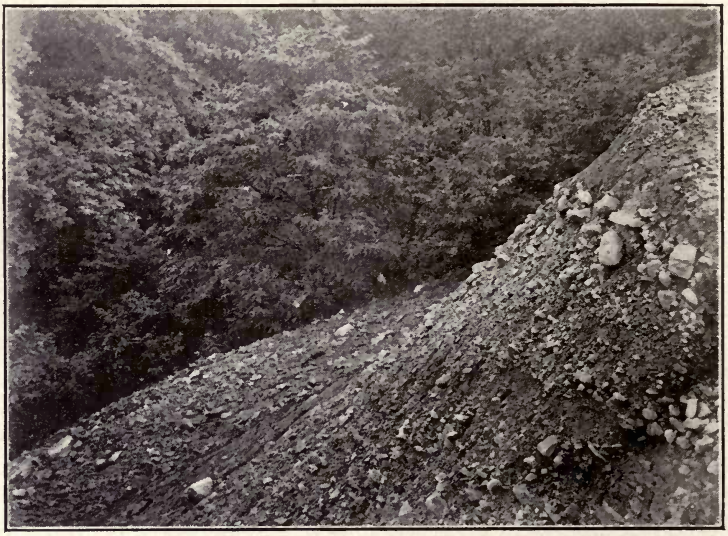

FIG. 35.—Detail of cutting in fan-cone from Antis Gap, showing rough assortment of strata.

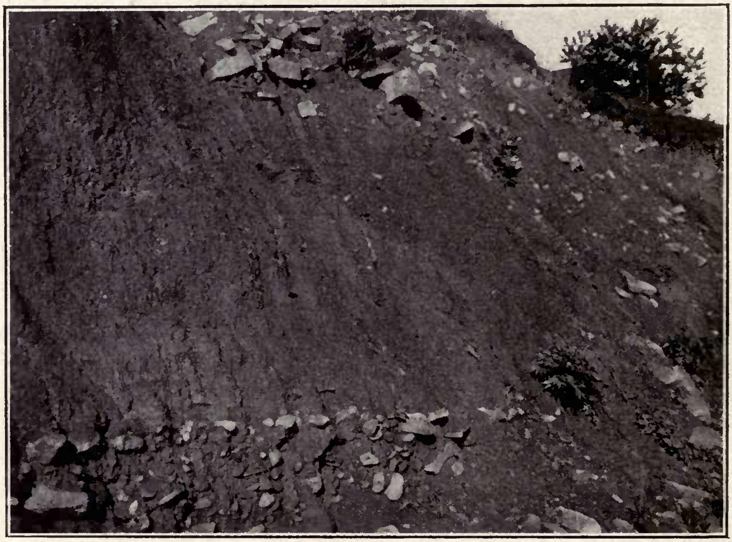

FIG. 36.—Section of fan-cone, showing drift overlaid by unstratified silt, and that by slope-wash from Bald Eagle Mountain, Mill Hall Gap, Clinton Co.

to Emporium Junction, Figure 38 shows a flat-topped delta formed from the material in the floods of Lake Wright forced over the Pennsylvania plateau through the Keating Summit trench in which the Portage Branch of Sinnemahoning Creek now flows.

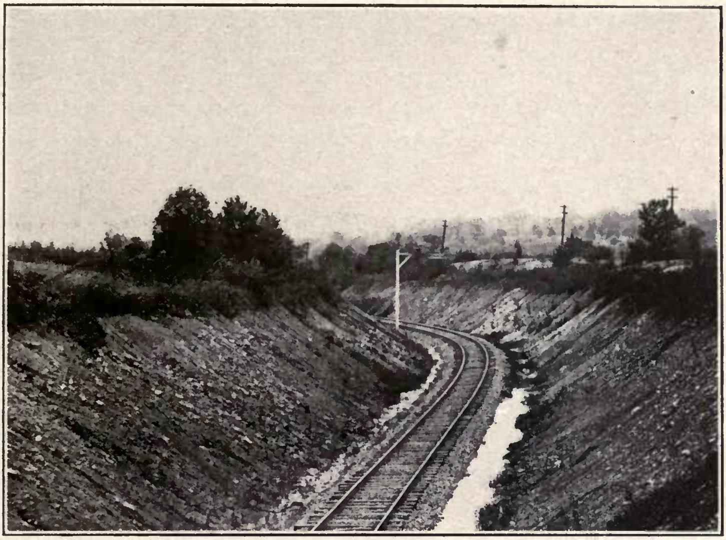

Fig. 37.—Cutting through Mill Hall fan-cone, Clinton Co.

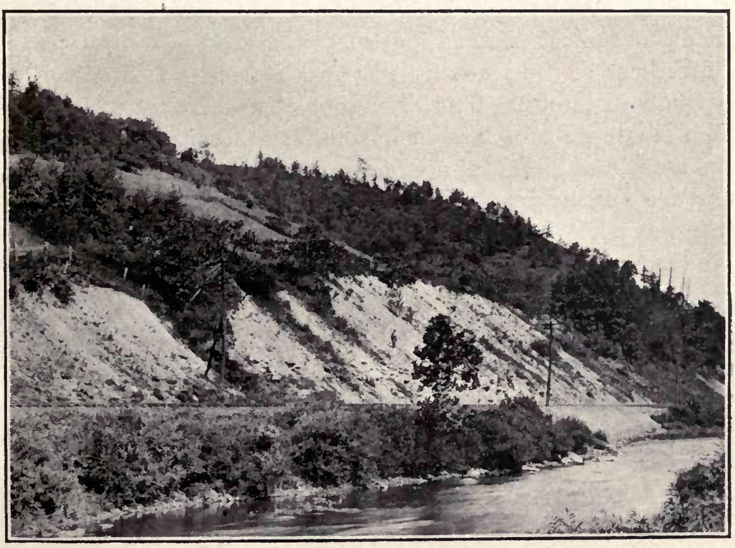

Fig. 38.—Cutting through fag-end of delta, Emporium Junction, Cameron Co.

It remains to say that the largest boulders found along the Juniata River are 3 feet in diameter; the average size, 2 feet. These are found in the top sands, indicating the presence of icebergs and cakes. There must have been a deep flow over the col at Dix to carry these and make a stream surface 80 feet above present stream level. The bergs clogged the narrows so that the flood-plain of Juniata River extends several miles up their valleys. This is sufficiently strong to be noticeable in the topographical quadrangles of the region. The carriage of sporadic patches of gravel 100 feet above the average of high water is noted in the preface references above noted, and was caused by the breaking of the ephemeral cloggings and the rush of the wave up an opposing hillside.

CHAPTER IX

HIGHLAND DRIFT. LOBE NO. 8

The Ontario-Genesee-Sinnemahoning lobe moved up Genesee Valley at an angle of thirty degrees with the trend of the main trunk of the ice-sheet. At Houghton the valley makes a turn of 50°, so that from a trend of S. 25° W. the trough slopes upward S. 20° E. On the west is the high wall mentioned in chapter one, which turned No. 8 towards the highlands of Potter County. There was thus a steep upward climb for this lobe, and no torrents or ridges to be crossed till past the line of the great moraine. In the drift of the mature phase we find crystallines in abundance. None have been found west of the trench at Keating Summit, as far as known. The local outcrops west of this trench are those of the plateau to the east—from Pocono (trench floor) to coal (plateau crests). The discharge of water over the plateau has made the elimination of foreign burden complete, and the inability of the right margin of No. 8 to mount the steep bluff of Mount Moriah left the basal ice and its burden across the Allegheny trough at Vandalia. The drift-sheet left by No. 8 was very thin and indefinite. The area it covered is thus divided:

Clarion River Headwaters.
Potter-McKean County Plateau.

Clarion River Headwaters.—The last statement about West Creek Summit was that 15 feet of silt covered the divide. Gravel is found 2 miles down Elk Creek Valley at St. Mary's, 20 feet above the stream, and occurs for some distance beyond, and sporadic patches of the same are found westward to Ridgway on Clarion River. The East, West and Instanter Branches of Clarion River are full of rolled and angular gravel in bars, terraces and flood-plains, in which boulders of large size occur. These slabby, angular and rolled deposits rise sometimes between 15 and 20 feet above the river. The Clarion is peculiar in the great number of small feeders that rise high up on the plateau, and head opposite similar small affluents of Allegheny River. The Clarion affluents leap into its trough, which is trenched throughout by materials brought by No. 8.

Potter-McKean Plateau.—The Johnsonburg Branch of Pennsylvania Railroad passes up East Branch of Clarion River to its source at Clermont (2080) where it crosses the plateau crest along a broad and shallow trough to the Mill Brook branch of Potato Creek. The region is smoothed and the surface dotted with rounded stones. Mr. Kiefer reported (1896) 15 feet of gravel in a cutting south of the town. At Wilcox, on the West Branch, a drive-pipe passed through a stratified outwash of glacial origin, as follows:

Surface soil and sandy loam	5	feet.
Loam and gravel	5	
Gravel and pebble	10	
Gravel and sand	5	
Gravel and pebble	5	
Gravel and sandrock	5	
Quicksand and pebble	5	
Fine sand	3	
Total	43	

Well drillers call sandless, waterworn gravel "pebble." This indicates that the peculiar sandless gravel of the Allegheny Valley about Warren is found on the plateau also.

The plateau shows the usual swampiness which is an evidence of glaciation on high levels. Katrine Pond Swamp (2300) is one of the largest of these areas. The region was briefly examined along the lines of railroads, which are more numerous at date than 20 years ago. The principal work was performed in connection with the spreading of the margin of the main trunk from the west. One of the evidences of the inability of No. 8 to send all of its breadth over the plateau is nicely shown in Mr. Leverett's map (preface note A, plate iv). The basal ice massed against the bluff south of Allegheny River, and the burdenless top passed onward to the crest, as will be seen later in describing the attack from the northwest. This ends the frontal work by lobes whose drift-sheets can be distinguished. The parallelism of the great moraine and the boundary of the Attenuated Border as shown in the frontispiece is not only interesting, but seems to have been the reults of depositions by different phases of the same lobes.

CHAPTER X

SOUTHERN MARGIN OF THE MAIN TRUNK. FLUVIATILE DRIFT

The patch-work stream called Allegheny River and its environment can not be divided into areas whose drift-sheets can be separated and discriminated, as can the lobal areas of the state. The story here is of ponding on a massive scale, of widely spread sediments, of similarity instead of discordance. It is necessary to ascertain the causes of the utter change in the character of the drift. Premising that the preglacial arrangement of the regional drainage of Mr. F. Leverett will be followed, with the exception that "Allegheny" will be used for his old Upper Allegheny System: "Tionesta" for the old Middle Allegheny System, and "Clarion" for the Lower Allegheny System, the following subjects will be considered:

The Geology and Present Topography.
The Preglacial Topography and the Cols.
The Glacial History:
- Glacial Lake Wright, 4 periods.
- Conewango Slack Water, 3 periods.
- Glacial Lake Leverett, 3 periods.

The Border of the Ice-sheet.

The Geology and Present Topography. *Geology.*—The vast amount of trenching performed in connecting the separate river systems makes it necessary to understand the difference between the rocks of the Pennsylvanian-Mississippian formations in the Anthracite and Bituminous portions of the state. In the latter the sandstones are porous, soft and so water-soaked as to form a huge reservoir where water can be obtained —even on top of the hills—by sinking to a depth of 100 feet. In a region subjected to severe cold this saturated condition aids the breaking-down of rocks, and especially along the lower parts of the canyons in which the streams flow, as there the reservoirs discharge through seepage springs at water level, and thus tend to maintain a square bottom section to the canyon. In the same manner this tendency to disintegrate under the action of frost helps to sharpen the spines of the narrow ridges between adjacent and parallel streams. The rocks have very perfect systems of joints, and readily break into cubes. The smaller pieces form the boulders which average 2 feet in diameter and attain a maximum of 3 feet; the largest are known as components of the "Rock Cities" which occur in the region. In both cases the results are due to glaciation; the "Rock Cities," to the settlement of the stagnant ice-sheet, as told in the beginning of chapter two.

Topography.—The prominent features have been given in chapter one. The Salamanca promontory extends 10½ miles north of the state boundary at an elevation of 2200, with crests up to 2400. In places its spine is less than 250 feet broad. Its end drops, in ½ mile, 820 feet to the filled flood-plain, and 1170 feet to the rock floor of the Allegheny River. The drop on the west side to where the same flood-plain enters the Big Bend trench is 1000 feet. On its east side is a drop of 700 to the flood-plain of Tunungwant Creek, which is carried at 1500 feet above ocean level one-third of its distance in the meridian into the Cattaraugus-McKean plateau. At Tarport there is a sudden rise to the crest of the latter. East of the Tuna trench is an extension of the McKean County plateau to the Allgeheny trench at Vandalia, with average elevation 200 feet higher than that of the Salamanca promontory. Its highest summit is Mount Moriah, and its drop is greater (900) and more abrupt than at the end of the latter.

Quaker Ridge extends from near Kane through the northwest corner of Warren County to Chautauqua County, N. Y., with a sharp spine that falls gradually to the northwest till it disappears beneath the trough filling of Conewango Creek at Kennedy, N. Y. (1300)—a fall of 800 feet. The great moraine crosses this ridge east of this trough. The regional quadrangles are referred to for the details of the present drainage system. Especial attention is asked for the one giving the region from Franklin southward to include Brandon, Kennerdell, the filled channels north of Egbert's Hill, between Polk and Takitezy, the trench south of the former, and at Fosters, as these substantiate the arrangement suggested by Mr. F. Leverett, Fig. 6, p. 135, preface note A. For McKean County see Mr. Ashburner's topographic map, vol. R, 2d. Geol. Surv., Pa.

The Preglacial Topography and the Cols.—The three profiles between Erigan Valley and the Allegheny trough have been given in chapter one, and explain the continuity of the high wall west of the Genesee Valley, the rise necessary to cover the plateau, and the inability of a lobe west of No. 8 to reach the latter by a frontal attack. No lobe could pass up the old Upper Allegheny Valley, as its trend was at but a slight angle with that of the main trunk of the ice-sheet. Any movement towards the McKean County highlands west of the high western wall of Genesee Valley, would be turned into the impetus favoring motion southwestward up Erigan Valley. The tendency to move towards those highlands was thus at right angles to the main motion, and, instead of being favored by the more continuous procession towards the Illinois boundary, was dependent almost wholly upon the increase in thickness of the ice-sheet over the trough in Western New York.

The southern part of the region to be considered was drained by the Tionesta (old Middle Allegheny) System. Its debouchment upon the Erigan Valley was west of that of the Upper Allegheny, and the closing of its valley mouth was thus subsequent to that of the latter. Once past the Pennsylvania plateau there was a chance for a lobe to turn southward along the eastern edge of Ohio. The position of the Conewango and Brokenstraw mouths, and the direction of their discharges are unimportant, as is, also, the ability to trace any of the buried streams of the region beneath their thick drift-sheet. These lines would have been of value had there been the slightest attempt of the great streams to resume their preglacial base-levels. The elevation of the ponded water was sufficient to disregard watersheds, to trench many cols and passes sufficiently to afford temporary relief, and to so cut down others as to completely change the drainage systems of the entire region; so that the present Allegheny River is formed of the parts of eight separate streams before reaching the preglacially dominant stream of the region—the Clarion. The greatest drop in the Allegheny floor below Warren is but 8 miles above its junction with the Clarion. It leaps into that deeply trenched stream, as do most of the Clarion affluents, and thus shows that the preglacially trenched Clarion base-level has but recently begun its movement up the younger stream.

Cols.—In view of what has just been said, the cols are most important in an estimate of where and how the work was done that formed Allegheny River, which is the subject of this part of the discussion. The first and most important consideration is the manner of making and the ease of forming cols in the soft and porous sandstones and shales of the Mississippian-Pennsylvanian measures. The stream floors have thrust their square-bottomed heads deeply into the mass of the Pennsylvania plateau. Either side of the valley has a somewhat uniform rise, and the rock floor maintains a uniform grade to within a few miles of the source, where it becomes a parabolic curve, and from 2 to 4 feeders leap into it from the crest of the plateau. A very good example is afforded by Potato Creek, which has one of its feeders rising in Cameron County. The stream flows across McKean County in the meridian east of Mount Moriah to join Allegheny River. The fall from the source is 450 feet for the first 2 miles; 100 feet for the second; 30 feet for the third; and an average of 15 feet per mile for several miles. There is a similar undercutting at the side bottoms, which extends upwards to form the thin spines, as noted in the Salamanca promontory. Rice, Limestone, and Red House Brooks are trenched into the mass of the latter. Between the first two, where the country road crosses, the breadth of the spine at 2000 feet is 250 feet. Between the first and last the spine at 2250 feet is but a few feet broad; at 2000, but 500 feet broad. The Quaker Ridge spine averages between 300 to 500 feet thick at 2000 feet, and but 200 feet thick at 2100 feet for 1 mile on either side of the Big Bend trench; while for 6 miles the average thickness at 2000 feet is 1700. These thin spines might hold quiet water, but waves of any force would batter, and an ice-sheet of any weight, crush such soft and porous walls with ease. The wrenching away of the crushed fragments by a torrent, or the battering incident to the passage of bergs and laden ice-cakes would without difficulty make an initial cutting of from 150 to 200 feet in depth, sufficient to start trenching across a crushed spine.

The following passes and cols enter more or less into the glacial history:

Keating Summit. Portage trench between the Allegheny and Sinnemahoning basins. Top of col at beginning of trenching unknown. Top of plateau 2400. Bottom of trench 1878. Cut in the meridian across the Potter County plateau, immediately east of the McKean County Line. Twenty miles west of the great moraine.

Clermont. Broad and shallow pass, with floor at 2068 between the East Branch of Clarion River and Mill Brook, an affluent of Potato Creek and Allegheny River. Twenty-eight miles west of the great moraine.

Glad Run. A shallow pass between the Allegheny (Kinzua) basin and West Branch of Clarion River, below 2100.

Kane. Broad and shallow pass, floor 2025, between the Allegheny (Kinzua) basin and, to the east, the West Branch of Clarion River; to the west, the Tionesta River.

Barnesville. Trench, 1500-1300, between the preglacial Conewango and Tionesta basins.

Thompsons. Trench, 1610-1000, between the preglacial Conewango and Tionesta basins. The upper level is half way between Mr. Carll's "at least 1800," and Mr. Leverett's "at least 1220."

Torpedo. Untrenched pass, about 1550, between Brokenstraw and Oil Creek basins. This is between Garland and Grand Valley.

Titusville. 1610—rock floor unknown, trench filled, between preglacial Upper and Lower Oil Creek basins.

Fosters. +1500—filled trench, rock floor unknown, between preglacial East and West Sandy creeks.

Foxburg. Trench, top between 1480-1450. Filled bottom, between preglacial West Sandy Creek and Clarion River. Located between Foxburg and Emlenton, but called after former.

The following are cut across Quaker Ridge between the filled Conewango channel (1300) and Big Bend trench, which last is included. They afforded a discharge between glacial Lake Wright and the Conewango Basin at Warren during the passage of the margin of the ice-sheet up the spine of the ridge. When it is remembered that the great moraine rests across that spine, east of the filled channel at Kennedy, it is at once seen that until the end of the Wisconsin period there was a clogging of the old channel of sufficient bulk to enforce the trenching of Big Bend col to its present depth, with a rock floor 200 feet below the filled channel at Kennedy, and a filled trench with surface 100 feet below the same. The following are arranged in their order from west to east:

Kennedy. Broad preglacial channel of Conewango Creek, now filled to 1250.

North Bone Run. Trench. Top about 2000: bottom, 1582. Leads from Mud Run on the Allegheny side.

Bone Run. Trench. Top about 2000: bottom, 1566. Leads from Cass Run

Storehouse Run. Shallow pass, floor 1925. Leads to deep trench from the east bank of Conewango Creek.

Reynolds Run. Broad and swampy pass, floor 2020. Leading to Ackley Run. The trench at the bottom is cut 2½ miles at 1500 feet into Quaker Ridge.

Big Bend. Trench. Crest marked 2154 on plate 1, vol. III, 2d. Geol. Surv., Penna. Today the sheer walls rise to 2040 and 2060 on the two sides. The rock floor is probably 1100, as shown by oil wells, and the filling is at 1200. The spine of the ridge immediately to the west rises to an average of 2100 feet above ocean level.

Glacial History. *Introduction.*—Comparative slopes for the main trunk and the various glacial lobes were obtained in chapter two. With the elevation of 8000 feet above ocean level for Lake St. Peter and a fall of 5.77 feet per mile, the elevation at a point where a normal to the trend of the lobe would pass through the Salamanca promontory would be 5000; the thickness above the Erigan rock floor, 5400+; over the Niagara promontory, 4400+. The present elevation of the Wabash watershed is 800. A drainage exit to Ohio River lay below 1000 feet. The average rise to the plateau from Erigan Valley was 2600 feet; to submerge the crests, 2900-3400. It is evident that it would require far less effort to move the front of the main trunk (300 feet high) towards the above watershed than to turn at right angles and rise 2000 feet to the top of the high wall of the Allegheny Valley. The same reasoning can be employed to show that No. 8 did not force water over the higher passes from the Genesee ponding until late in the glacial history of the First Phase. The aged-appearing drift-sheet of Northwestern Pennsylvania is thus of necessity much younger than that left by No. 3.

The calving of bergs from the Ontario rock shelf into the ponded water in Erigan Valley has been noted in chapter one. The carriage of native copper in an ice-cake to Warren will be told below. Bergs and cakes must have come down Professor Spencer's Laurentian River with this metal. How they came to sail across the slack water in the Conewango Valley is unimportant. The fact remains that they did so, and they carried not only this metal, but Canadian rocks so friable that they would have been crushed to powder if incorporated in the ice-sheet. We have thus the certainty that some of these ice-cakes managed to remain unincorporated with that sheet. The largest bergs could enter the submerged mouth of the old Allegheny, as the depth of water was greater than 900 feet—probably 950.

Why the regional *facies* is fluvial is told in chapter three, which describes the work of the torrent in the marginal canyon; the gradual pushing of this trough up the hillside; the levitation of the silt from the surficial mantle; the origin of the heavy drift-sheet in the valleys; the washing of ridge crests; the formation, in fine, of Mr. F. Leverett's "stony till" (preface note A, p. 223). The order and succession of the causes which produced these will now be considered.

Glacial Lake Wright.—The reason for this name is given in chapter three. Its greatest area was 5000 square miles: its elevation varied between 800 and 2150 feet above ocean level. It covered the Upper Allegheny, Conewango and Brokenstraw basins, and was surrounded by those of the Genesee, Sinnemahoning, Clarion, Tionesta and Upper Oil Creek. Its bottom was crossed by the great moraine at Kennedy and Vandalia, and by the boundary of the First Phase at Clarendon, though the last place was not included in its area when that boundary was laid. It discharged at times through several of the passes and trenches of the above lists.

Period One began with the separation of Upper Allegheny Valley from the ponded water held against the Wabash watershed, and ended when the water level was raised to 1500 and a discharge over Barnesville col began. This level ponded the water to Port Allegany, N. Y. and the Cuba pass, both in the Allegheny Valley; to above Roystone in the Tionesta Valley; almost to the Torpedo pass into Grand Valley, and to within 100 feet of the col at Thompsons. Warren, Irvineton, Glade, Stoneham, Clarendon were submerged over 300 feet. The discharge was entirely through the marginal canyon of the ice-sheet as it was spread higher up the southern margin of Erigan Valley.

The deposits were of three kinds: The *orogenic*, see scheme, always red, and found as slope-washes and beach deposits; the gravels, sands, and clays from No. 8 discharged through Cuba pass; the stony gravel from the marginal canyon. The first and third were continuous and will not be again mentioned. The first is found against the scoured rock-floor at Stoneham, Clarendon and Sheffield, in spots. It is 25 feet thick at State Line, and 8 at Smethport. There was no distribution of the second sort till the next period.

Period Two begins with the discharge over Barnesville col at 1500 and ends with the discharge over the Pennsylvania plateau. The elevation of Barnesville col is indicated as above 1480 by the deposits at Clarendon at a later period.

Conewango Valley was separated from Lake Wright during this period, and its history will be considered separately. The advent of the glacial margin and its gradual movement up the spine of Quaker Ridge developed discharges over that spine through the cols in the second list. In time the level of the Keating col was reached and discharges over the plateau began, at a lower elevation than the col at Big Bend, and all secondary to that along the marginal canyon, wherever that may have been situated. The reversed flow up the Conewango and over Barnesville col was by a current that never exceeded in velocity 7 inches per second. A very good example of the sudden broadening of valley area in a reversed flow is shown by measuring the distance between any series of contour lines, as 1500, across the Conewango Valley from State Line to Watson.

Remembering that this valley was flooded 300 feet deep, and that a current below 7 inches per second passed through these narrows and suddenly broadening hollows south of them, we can understand the sudden checking of the current over the latter, and expect the deposits we find there, while none exist in the narrows. The Indian Hollow deposits will be considered later. The sudden increase in area there to twice that of the narrows immediately above gives the reason for their deposition. As the direction of the current has been maintained to the present day these deposits have been protected from scour by the same agencies that caused their formation. There are so many places away from the subsequent lines of scour, as the cove south of the Oakland Cemetery bar, that a complete valley filling must of necessity have left equally large deposits, or, at best, beach lines, to show the continuity of that filling. These are not found for the reason that the current which brought, and from which the Indian Hollow deposits were dropped, did not pass across that area, but moved from Warren to Glade and thence to Barnesville.

Deposits.—(See scheme at end of chapter four.)

Early Fluviatile Outwashes—A. Conewango Clay.—A sticky blued clay mixed with vegetable fragments and surrounding large piles of logs. This is found continuously from Olean to State Line, Indian Hollow, Glade, Stoneham, Clarendon, and the northwest edge of the swamp at Watson. Thin patches are found at Sheffield. As the main drainage was through the marginal canyon this must have come through Cuba pass to represent the deforestation and removal of the surficial mantle in Genesee Valley by No. 8. It is *Highland* material levitated and distributed by *Fluviatile* agents, and thus becomes the lowest of their deposits. At Sheffield it shades into the *Orogenic* wash, a section of which is shown in Figure 39. Its included logs and chips are water-soaked and soft but not decayed. Their sharp edges and splinters resume their hardness, but not their original weight, on drying. As far as known this is absent from the Brokenstraw Valley—certainly from its mouth. It is 100 feet thick in the Conewango Valley. That in Tuna Valley is from the same source, but of a later period. This subject will be more fully considered under the Conewango Slack Water.

Period Three begins with the flow over the col at Keating Summit and ends with the beginning of the flow over Big Bend col. The variation in the elevation of the ponded water was between 1878 and 2150 above ocean level. The trenching of the former was stopped by No. 8 which we have found across the headwaters of Clarion River, and thus across this trench. A flow across the McKean County plateau produced results similar to the cloggings in the Juniata narrows, as the icebergs hindered the flow across the various passes, and prevented decided trenching. There was now a reversal of current in Tuna and Kinzua valleys, and blued clay was deposited, which fell about huge log piles in the former, and is 100 feet thick 12 miles from the Allegheny. It is 30 feet thick in the upper part of Kinzua Valley at 1700 feet above ocean level. This march of No. 8 across McKean County was coincident with its crossing the high western wall between Genesse Valley and the Allegheny trench, and its massing against the bluffs below Mount Moriah. The elevation of ponding is shown in the distribution of the drift below 2000-2050, the washing clean of the small areas of crest above that level, and especially by the manner in which the drift is thrust in slight tongues into the mouths of the small streams that flow down from that mountain. The basal ice thus checked, there was the usual shear, and the clear top ice passed over the plateau top, carrying the same sands and mixing them with the small local fragments on top

FIG. 39.—Red *Orogenic* drift, Sheffield, Warren Co.

of the deposit of clay. We have thus two kinds of drift from No. 8: that from the southern margin rolled and mixed with angular pieces, as described over the Clarion headwaters: found at Emporium Junction over 100 feet thick: at Clermont, 15: at Wilcox, 43, etc. Here also is to be placed the 125 feet of red gravel at Sheffield from the flow at Kane. This gravel and sand are interstratified at Wilcox. This is *Late Highland* drift, and it overlaps the *Early Fluviatile* clay.

Period Four begins with the flow over Big Bend col and ends with the trenching to its rock floor, now 100 feet below the Allegheny stream bottom—a total cutting of 1000 feet. The margin of the ice-sheet was at or near its farthest advance at the beginning of this period, though it was by no means near its boundary farther south.

The marginal canyon was not mentioned in the discussion of the last period, though it is evident that it must have been approaching the region, as its location depended upon the lowest available outlet into a basin uncovered by ice, and as the margin covered the lower avenues of escape, it sought ever the lowest of those that remained. The trenching of Keating col indicates a torrent, but one swollen, perhaps, by No. 8. It is possible that the marginal canyon discharged eastward into the Susquehanna until No. 8 crossed the Keating trench, as Professor Fairchild has shown where various flows passed thither. It is a matter of indifference, however, whether all the marginal flow passed, as it probably did, across Big Bend col. What passed was sufficient for the purpose, and the col was trenched. When we remember that the Kennedy channel from the Upper Allegheny Valley to that of the Conewango during all this time was at or below 1250 feet above ocean level, we understand that the ability of trench Big Bend was entirely dependent upon the presence of the glacial margin across that channel and the spine of Quaker Ridge to the col at Big Bend. That the ice passed beyond that col is shown by the moraine at Clarendon. That it remained at or beyond the Kennedy Channel is shown by the depth of the trenching, as well as by the presence of the great moraine between it and Kennedy. The level of the ponding in Conewango Valley was at least 1600 at this time. There would be a fall of 500 feet between the Lake Wright and Conewango levels. This, in such soft and porous rocks, and down a stream with a parabolic channel-head, would produce a water-fall and rapids sufficient to undercut the rock over which the fall occurred. There was probably no very long duration to the intense first period of trenching.

The *Deposits* from No. 8 were a continuation of those described in the previous period. To these must be added the drift from the lateral margin of the main trunk. In the Kinzua Valley we find the blued clay at the mouth of Glad Run. At lower levels we find local discoidal gravel laid in foreset bedding and dipping downwards against the present stream, to show the reversal of the current. The surface deposit is of sand, as over the plateau about Kane and in the valley of Sugar Run which adjoins to the north. In the sand are fragments of sandstone and shale, boulders of sandstone and conglomerate, and masses of 12 × 12 × 4 feet. The shales are red and of other colors, and there are many small quartz pebbles from the decayed conglomerate. These are all from local outcrops, and the materials differ entirely from those of the present Allegheny flood-plain, which abound in crystallines. Although there is a continuation of this flood-plain level up both the Kinzua and Sugar Run valleys, there is a stoppage of the crystalline material. In the valleys north of Sugar Run that rise in the Salamanca promontory this is not the case, as there the crystallines are found in the drift as well as in the flood-plain. We also find crystallines in the Conewango Valley, south of the Kinzua. This and Sugar Run are peculiar in being free from crystallines in the drift, while the valleys to the north and south contain them, but of different kinds, which adds to the variety. The tendency of the drift to become local has made the difference. The movement of the glacial margin at Warren was parallel to the spine of Quaker Ridge. From its summit the advancing ice-wall lay across the Allegheny trough on the north, and the Conewango trough on the south. It scraped upon the Kinzua and Sugar Run outcrops the precisely identical rocks from the ridge: into the valleys to the north, the drift already washed into the old Allegheny trough: into the Conewango, and to Clarendon, the drift accumulated in the old Conewango. As for what is in the present Allegheny flood-plain across the Kinzua and Sugar Run mouths, it was not there at the time, as Quaker Ridge was intact: Big Bend col, untrenched, and the present Allegheny trough then lay in the mass of the ridge. Before leaving the subject, attention must be called to two wave-built terraces, 110 feet apart, reported by Mr. Barrell, with elevations approximately (barom.) 1500 and 1600, showing sandy beach lines, while between them the valley sides are rough and stony. These can be traced several miles from the valley mouth (Sugar Run). The reddish clayey silt in which they are cut carries polished sandstone boulders from 18 inches to 6 feet in diameter.

Sculpturing.—There was a stoppage in the trenching of Big Bend col at 1500, which is near the level of the lower terrace just mentioned. It is also the elevation of Port Allegany, N. Y., where the broad, flat and filled Allegheny Valley bottom—level on a cross-section—changes to one V-shaped and narrowing, with the angle of the V growing sharper, and the stream floor rising. The slope of the river trough from the source to Port Allegany is 8.3 feet per mile: thence to Olean, 1.8, or one-fifth as much. This 1500-foot valley floor remains in patches in the race track and on top of the hill at Olean. One of the Salamanca terraces is near that elevation. The Cuba pass from glacial Lake Genesee is 2 feet below it. This level will be referred to when we consider the Conewango ponding. The remainder of the history of Lake Wright is so associated with the latter, that we will consider the final trenching of Big Bend col in connection with it; merely premising that the suction and scour of the current flowing through the trench as thus far sunk had not influenced the bottom filling of the old Allegheny trough. That occurred later.

Conewango Slack Water.—*Period One* of this ponding was identical with the same period of Lake Wright, as stated in the story of that lake.

Period Two begins with the discharge of a small portion of its water over the Barnesville col, and ends with the closing of the old Conewango

Valley by the ice-sheet, whose margin was at Clarendon. It comprised four epochs:

First Epoch.—To the complete separation from Lake Wright.

Second Epoch.—From the closing of the old trough at Kennedy by the ice-sheet, to the discharge of Lake Wright over the spine of Quaker Ridge above 2100.

Third Epoch.—From the closing of the Quaker Ridge passes to the discharge of Lake Wright over the Pennsylvania plateau.

Fourth Epoch.—From the discharge over the plateau to the closing of the Conewango channel and the cessation of a flow from its ponded water over Barnesville col.

During the first two the bulk of the ponded water was discharged through the marginal canyon, and but a small volume came from Warren to Barnesville. The bulk of the torrent that trenched that col came from Kane. The bergs and ice-cakes escaped through the marginal canyon. The approach of the glacial margin brought its canyon into the region. Wherever it discharged, it did not do so through Brokenstraw Valley. The duration of the second epoch must have been considerable, as Bone and North Bone trenches were probably sunk 300 feet each, and not together. There was also the deep trenching of the heads of Ackley and Hemlock runs.

We now come to the flow from the plateau about Kane through the affluents of the old Conewango (present Tionesta) source. The stoppage of the blued clay at the northwestern edge of the swamp at Watson has been mentioned. Without a stronger flow from the east that clay should have been spread to Barnesville: it stopped 4 miles from the col. Even after the glacial margin came to Clarendon its crystalline and local rolled gravel stopped before reaching Watson, and 5 miles from Barnesville. There are no crystallines in the Tionesta below that place till we reach the bar across the mouth, produced by another cause, as will be noted later. From Kane, therefore, came the 125 feet of red gravel at Sheffield, and the rest of the burden of the torrent which trenched the col.

Deposits.—Under this heading in period two of Lake Wright the continuous deposition of clay was stated to have occurred in this period also, and that the glacial scheme there introduced would be repeated under the present heading.

Early Fluviatile Outwashes—A. Conewango Clay.—The scoured rock-floor is rarely covered with *orogenic* slope wash or gravel. Generally in the Conewango, Allegheny, Tuna valleys the sticky blued clay is against it with logs and wood fragments. On the north side of Indian Hollow the writer took a piece of hemlock from it 1 foot above the scoured rock floor, and 20 feet below the surface. Oil wells show that this scoured floor slopes toward and beneath the stream floor, and that before any deposition took place there was a deep cove behind the shoulder of the projection from Quaker Ridge. Clay also caps the rock cutting of the railroad opposite Glade, and drive pipes show it beneath the gravels there. It does not underlie the Allegheny flood-plain, and is absent beneath the Brokenstraw deposits. It varies from 100 to 200 feet at Stoneham, as will be noted later. At Clarendon it is 100 feet thick against the rock floor at a point 48 feet above and to one side of the trough bottom. A little farther south, and where the torrent from Kane during the beginning of the ponding sent its burden, it is 130 feet thick, but overlies 102 feet of red *orogenic* gravel. At Tiona the Kane and Warren currents met, and the blued clay is intermingled with a flaky local wash. Like the Indian Hollow cove this Clarendon area is where there is a sudden broadening of the valley section to thrice the area of the narrows immediately to the north. This clay for a time was carried to Sheffield. In one place it is 2 inches thick: in another, 10 feet. It rests on red clay, either clean or mixed with red gravel.

It remains to consider whether there was a complete filling of clay over the valley at Warren. Its absence from beneath the present flood-plain and from beneath the Brokenstraw gravels proves that if originally deposited in those places it was completely removed before their deposition. Figure 41, to which reference will be made, goes farther and proves that it was never generally deposited, and that these classical deposits at Indian Hollow and Clarendon, like those at Brandon and Kennerdell, were deposited in the "holes" in a reversed flow.

Early Fluviatile Outwashes—B. Lower Indian Hollow Sands.—These fine sands are 60 feet thick (drive-pipe section) and dip in foreset strata southward 17°. After deposition they were smoothed along a horizontal plane 1316 feet above ocean level. They are divided into:

1. Quicksands, assorted and free from clay, lying on the clay or the rock floor.
2. Interstratified fine sands and rock meal with lenticules of clay (both clean and sandy). The total thickness of these and the underlying quicksands and clay is 160 feet at a point from 60 to 75 feet above the rock floor of the valley trough. The average dip varies between 20° of the top beds and the gradually decreasing values of the underlying beds.

Figure 40 shows the east side of the sand workings. The dark stratum gives the dip. The soft appearance of the surface indicates the fineness of the sands. The oil well in the background afforded the section of the formations here. The workings have considerable breadth. On the opposite side Figure 41 shows conclusively that there was no uniform filling of the valley with sand, but that the strata were dropped in the slackened water behind the projection from Quaker Ridge. On comparing the strata here and in the preceding figure it is evident that the latter (40) shows an area away from the scour of the current. The narrow dark strata run across the face of the working with little diminution of thickness, and the conditions of deposition were the same on the right and left of the figure. Figure 41, on the contrary, shows a spot just on the edge of the line of scour. Each bed thins out towards the left, where it comes within the area of the latter. In other words there were two areas at the time: one of deposition in Indian Hollow: the other of scour along the Conewango channel and over the hillside above Warren, where

FIG. 40.—Lower Indian Hollow sands, east side, Warren Co.

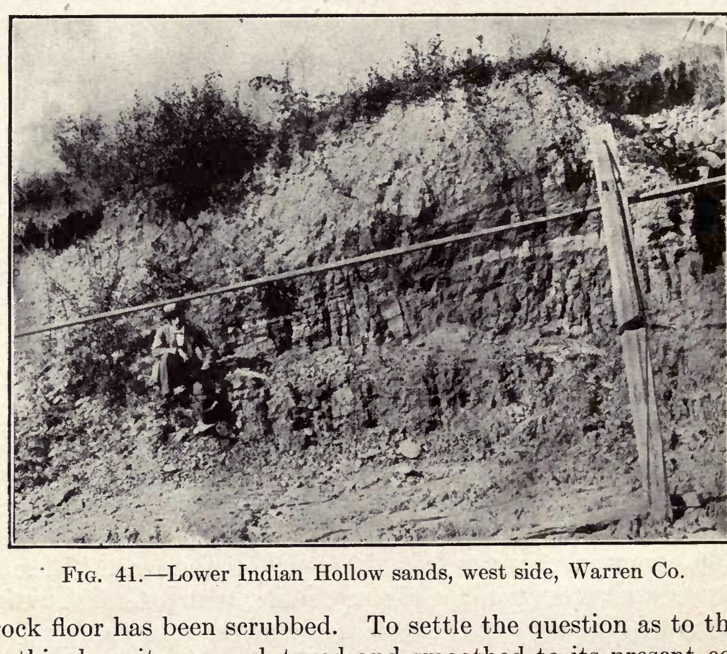

FIG. 41.—Lower Indian Hollow sands, west side, Warren Co.

the rock floor has been scrubbed. To settle the question as to the time when this deposit was sculptured and smoothed to its present contour, *Leverett Clay* with its iceberg burden caps the whole, and tells us that as we see this section today, so it appeared before the water level had sunk below the top of these sands.

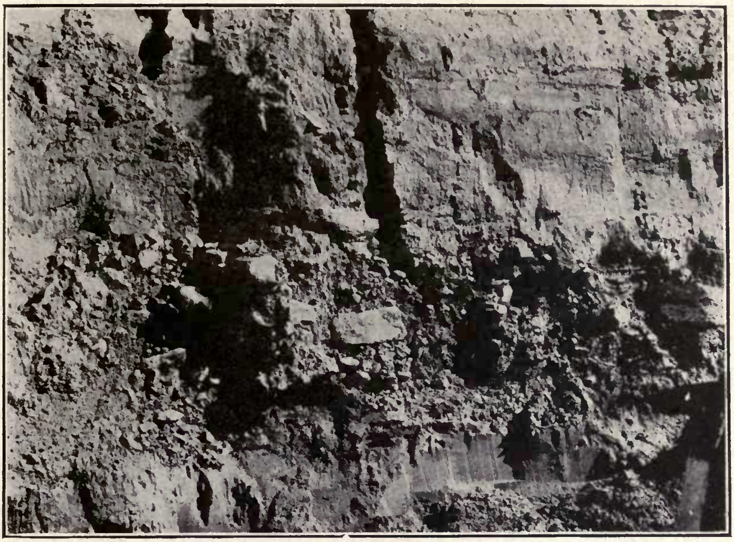

Fig. 42.—Clay lenticule with iceberg burden, in Lower Indian Hollow sands, Warren Co.

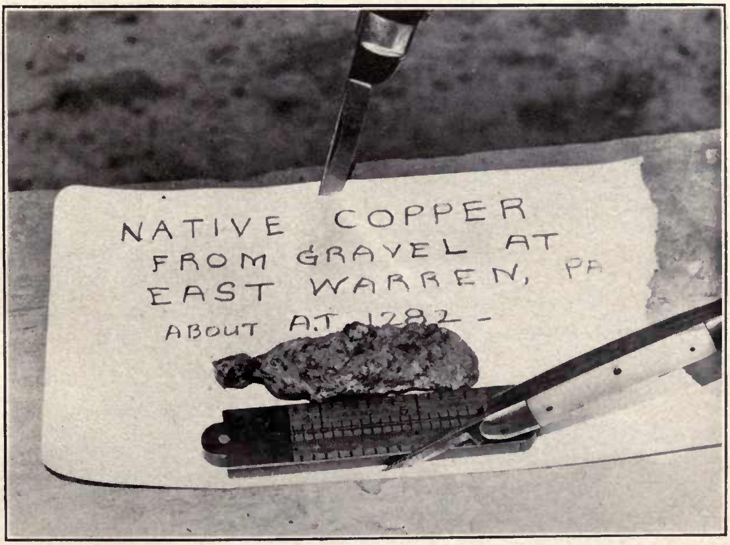

Fig. 43.—Native Copper nugget, clay lenticule, Lower Indian Hollow sands, Warren Co.

Figure 42 shows a 14-inch lenticule of clay 6 feet long, at 1285, carrying fragments dropped from bergs, among which was the nugget of native copper of Figure 43. This last was covered with a film of oxide 1/32 of an inch thick. A shovelfull of the lenticule and inclusions showed that the latter formed but one per cent. The foreign rolled pieces were the

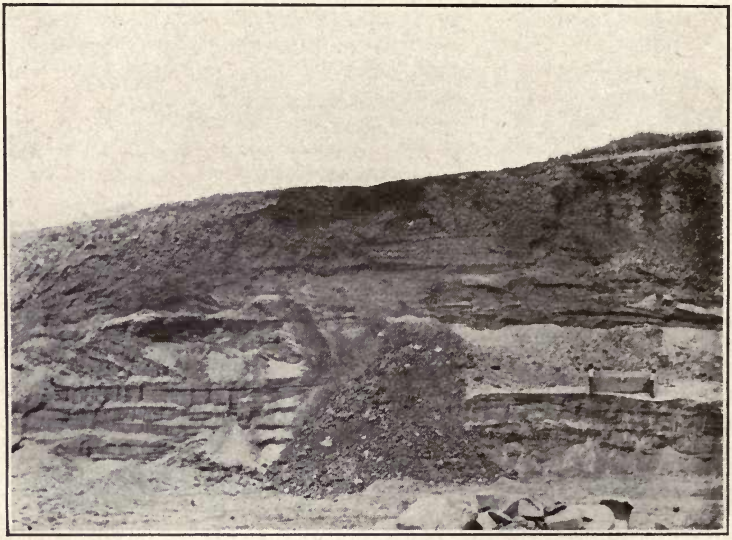

Fig. 44.—Upper Indian Hollow sands, Warren Co.

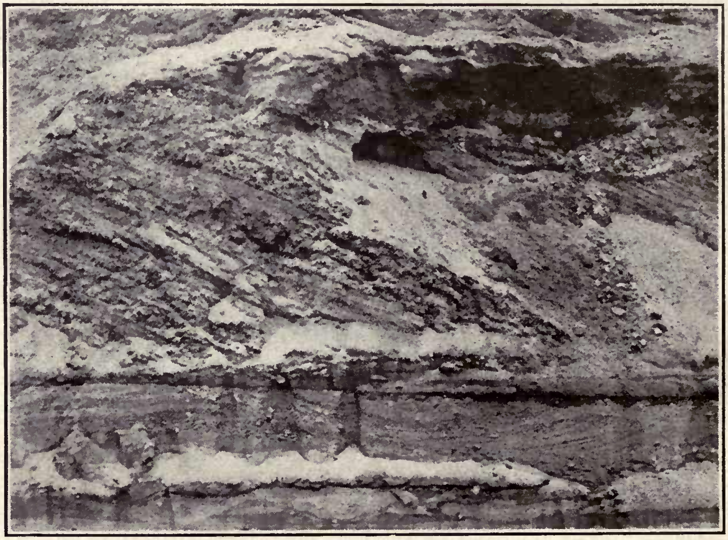

Fig. 45.—Detail of plunge and flow stratum, Upper Indian Hollow sands, Warren Co.

same proportion of the burden. Of the pieces over 1/2 inch mesh 11 per cent. were rolled. Here again there is an approximation to local angular material.

Upper Indian Hollow Sands.—This series of coarse sands and fine gravels (¼ inch) is 20 feet thick, and laid in wavy strata nearly horizontal (Figure 44). Fine gravels are interstratified in thin layers. At 1321 is a bed between horizontal strata, with plunge-and-flow foreset bedding dipping north, or against the dip of the other beds, as, Figure 45 if the suck of the marginal canyon had obtained during its deposition. The top of the series is 1336 above ocean level. The particles are fresh and free from rusting. The same series of blued clay, sands and fine gravels is found at Clarendon, but at different elevations, the top of the sands being 1443, or 107 feet above the Indian Hollow top. This is another proof that there was no even filling of the valleys during this period. Had there been such a filling, or had it been continuous, there would have been a connec-

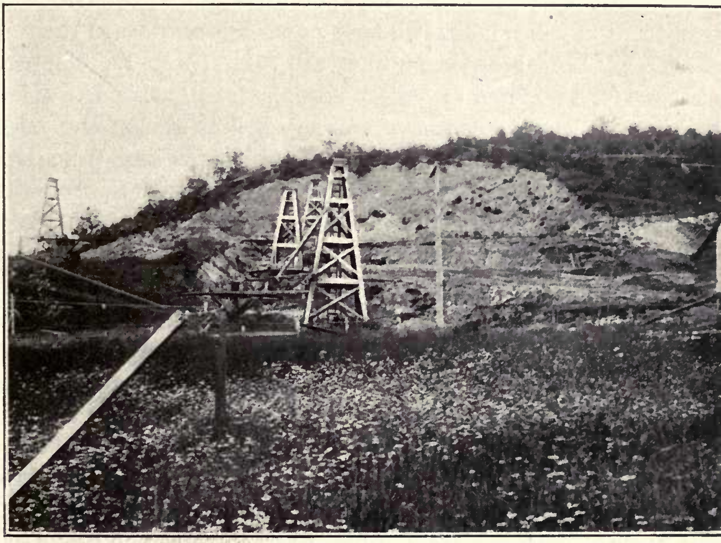

FIG. 46.—*Clarendon* gravels on top of Upper Indian Hollow sands, East Warren, Warren Co.

tion between Clarendon and Indian Hollow shown by the slopes of the strata along a uniform dip.

Middle Fluviatile Outwash—Clarendon Gravels.—About Warren these are found below 1500 feet above ocean level. As their connection with the underlying beds is best studied at Indian Hollow, we will examine their section and arrangement there. Figure 46 shows the eastern face in the summer of 1897. The oil well on the extreme left is the one shown in Figure 40, with base at 1336, which is the elevation of the bottom of these rusty gravels. The top of the cutting rises to 1396. Their highest point as a continuous body is 1488 upon the shoulder of the ridge 2300 feet distant. Sporadic patches are found higher up. The height of the face is 60 feet. The thickness is 20 feet 700 feet up the slope. The foreset dip of 17° is shown in Professor Wright's Ice Age in North America, 5th ed., 1911, Fig. 55, where the clean sand stratum is shown, similar to one at Clarendon, thus showing the same succession of outwashes. These gravels were sculptured to their present contour during the ponding of the Conewango, as shown by the capping of the *Leverett Clay*. There was thus no general valley filling of gravels.

They are found in the basins of Hook's River, Dutchman's Run, and about Glade and Clarendon. At the last place they are of three varieties, and in three belts trending N. 38° E. That to the southeast rises 8 feet above the swamp, and is inconsequential. There is a railroad cutting 629 feet long through the middle one, and at 1480 the sides rise 5 and 8 feet above the track. The station and platform are on this. The third ridge is 660 feet northwest of the middle one, and extends over the railroad crest to Stoneham. The highest point of continuous drift in this ridge is 1515.52, but sporadic patches are found higher. The greatest thickness thus far known is 71 feet, overlying stratified sands. The front contains almost all of the foreign and crystalline rocks: the middle is subangular and local, with the rolled pieces decreasing from front to rear, and a minute inspection necessary for their detection on the surface: the rear (northwest) resembles orogenic drift. The margin rested here long enough to bring up the retarded basal burden, or the foreigners may have been pushed ahead in an accumulation of ice-cakes. If so, these were incorporated in the margin and not floating—otherwise we should find their burden dropped along the channel to Barnesville. The stoppage of these gravels at Clarendon tells us that the marginal canyon did not pass to Barnesville, and that the torrent from Kane still was sufficiently strong to push back whatever came from Clarendon. The original thickness of gravel at the latter place may have been greater, as will be considered later.

Of the same period, but different in character are the gravels of the bar opposite Irvineton, from, and at the mouth of Brokenstraw Creek. In them are well-polished pebbles and cobbles of pink and white quartzite, much rolled Pocono, fossiliferous Catskill and a few crystallines. These are in loam mingled with local material. The surface is covered with Pocono cobbles. The proportion of crystallines is smaller than at Clarendon, and there are boulders several feet in diameter. At milepost 227 (P. R. R.) there is a gravel deposit of similar character with foreset bedding dipping towards Warren, and underlying the flood-plain gravels. There are no indications of a flow over Thompsons col at this time.

Period Three begins with the closing of the Clarendon channel, and ends with the trenching of Thompsons col to its present rock floor. It must be remembered that the bottom of the trench in Barnesville col was about 1450 when this closing took place. The present level of its trench (rock floor) is 1300. The trenching of this 150 feet has thus no connection with the ponding in Conewango Valley. There has been a subsequent flooding and reduction of water level, as this trench is filled 60 feet and there are two terraces between which the present stream flows. There is thus a considerable history of operations that took place during this period outside of the Conewango Valley, and in what will hereafter be a part of the Tionesta (old Middle Allegheny) system.

Drainage.—After the stoppage of the discharge to Barnesville another and higher exit became necessary. The level of ponding about Titusville is 1610.64: the col at Thompsons was slightly higher: that at Torpedo, 100 feet lower. Grand Valley was thus flooded when the water rose to the Titusville col, and the ponding extended down the Upper Oil Creek Valley. The higher elevation of Thompsons col is inferred from the finding of slack water evidences south of Oakland Cemetery above 1610.64. There seem to have been three epochs of drainage:

1. Discharge through Grand Valley and over Titusville col.
2. Closing of the above by ice-margin, and discharge over Thompsons col.
3. Trenching of Thompsons col to present level.

In all of these there was never sufficient lowering of the water level to bring the Torpedo pass or the drift-sheet in Grand Valley within the line of scour. During the first of these, Grand Valley received a levitated deposit: during the second the outwash drift from the ice was laid down: in the third both cols were not trenched sufficiently to permit scour in this valley before the stagnant ice was removed. We have, thus this oldest of the drifts of the region with its original irregular surface.

The third epoch was correlated with the end of the last period of glacial Lake Wright. Whether it was with the period of deposition of *Leverett* Clay is unknown, as all of these valleys were again flooded to 1500 when the level of Lake Leverett rose suddenly to that elevation at the time the ice-sheet closed the mouth of West Sandy Creek and forced the discharge over the col at Fosters.

It remains to consider whether the Clarendon gravels were not originally of greater thickness. The stagnant ice probably remained for some time at Clarendon. If it did not, why was there no return to a flow over Barnesville col, as the present elevation of gravels at Clarendon is but 1513.32? There was a continuity of life in the ice, as witness its arrival afterwards at Titusville, and still later at Franklin and Foxburg. There was once as great a filling, and of the same gravels, in Hook's River basin, but only the traces remain. There is the same gravel at Stoneham as at Clarendon, and in a continuous sheet, but while it rests on sands at Clarendon, it has been dropped on the underlying clay at Stoneham. Now the highest point of the present gravel deposit is between the two places. It looks, therefore, as if the loss of 100 feet of underlying sands at the latter place had taken away 100 feet of elevation of gravel from the apex, and that its original elevation was about

1600 feet. This would show why a head of 100 feet of ponded water about Warren and above the present top of the gravels, was unable to force a way towards Barnesville, and by so doing distribute the crystallines towards that place, and into Tionesta River. There was a strong agent at work which had no trouble in removing stagnant ice, but when it did so Thompsons col was trenched below 1500.

Middle Fluviatile Drift—Land Laid.—This varies with the local outcrop, and some of its varieties will be described in locating the boundary of the Attenuated Border. In all cases there has been an insistence upon finding a crystalline piece in a deposit above the regional ponding. This limited the chances and made them far apart in the north. In the south where nearly the whole of the glaciated area was submerged the chances of discovery were fewer. Below Foxburg there is a general submergence.

Late Fluviatile—Reworking of Old Gravels.—The shapes of the river troughs, the fall of 500 feet from Lake Wright to the Conewango level, and the thin and soft character of the Quaker Ridge spine at Big Bend have been described, with the chance of undercutting at the fall. It is probable that during its erosion Thompsons col was likewise trenched, so that the fall of the level of the ponded water in Conewango Valley kept pace with that in Lake Wright, especially as in addition to the flow over Big Bend col there was added the accumulations of the Conewango and Brokenstraw valleys. The first effect of the Big Bend torrent was the clearing away of the stagnant ice from the col to Glade, Warren, Irvineton and Thompsons col. This would form a canyon with ice walls between which the torrent would flow. The clearance would begin at the top, and would be in a straight line. As it worked downwards it would cut into and remove projections from the valley sides. In this manner 1000 feet or more of the western end of the ridge between Morrison and Ott runs has been removed, and from 1500 feet to half a mile from the one between the latter and the old channel of Brokenstraw Creek, where it turned north to join the Conewango. This cutting is well shown along the railroad opposite Glade. The northern end of the ridge points its wedge toward Warren to deflect subsequent currents from the deposit behind it against the hillside northwest of Warren, where, below the 1500-foot contour half a mile has been cut away.

The clearance of the gravels from Hook's River occurred at this time, as did those in the present Allegheny channel from Glade westward. Dutchman's Run was also cleared of gravel, but, when the gravel was removed, the underlying sands were exposed, made quick by the water and run out as far as Stoneham, leaving the dense clay, and dropping upon it the gravels beyond the influence of the scour. For example, 300 yards east of the P. R. R. station at Stoneham the rock floor is at

1115 with 210 feet of blued *Conewango* Clay on it. At the foot of Bald Hill are 130 feet of this on *orogenic* gravel. Nearer Clarendon 30 feet of gravel remain above 100 feet of clay. The sands are gone completely. We are now in a position to conclude that when this dropping of gravels occurred, and this clearance of ice from the channel took place, that Thompsons col had been trenched below 1500 feet, or there would have been a return of the Conewango discharge over Barnesville col. This brings the following deposits within the *Late Fluviatile Period*, and at a time long after the formation of the *Clarendon gravels*.

Early Big Bend Gravels.—These were dropped in the broadening of the ice canyon beyond the most western of the wedges above described, and where the old Brokenstraw channel lay, in a long bar which is thrust

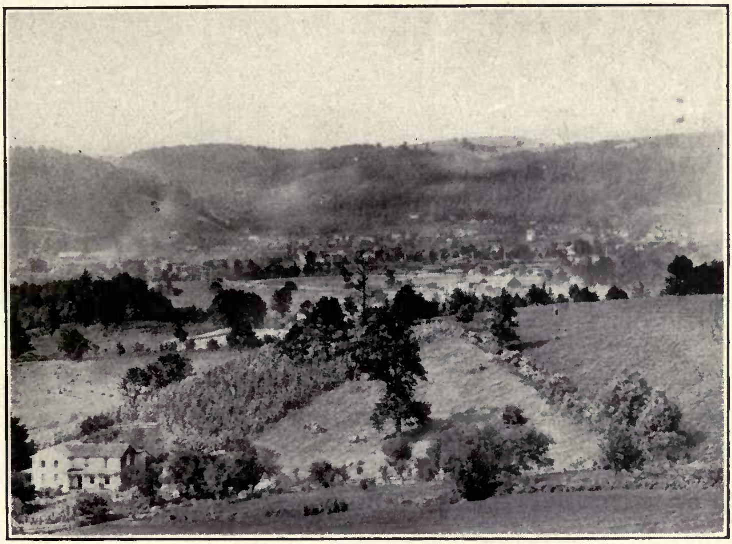

Fig. 47.—*Early Big Bend gravels*, Oakland bar, South Warren, Warren Co.

with gradually diminishing elevation across the plain, and on which Oakland Cemetery is now located, the end of which is shown in Figure 47. The light streaks above the top of the corn field are the end of the terrace-like bar of the *Middle* and *Late Big Bend* gravels. This gives an excellent idea of the great difference in the elevations of the two formations. Still lower is the Allegheny flood-plain. Warren is in the left distance. The bar is similar in formation to those in lakes Packer and Lesley. It is foreset bedded, shaped during the prevalence of slack water, and capped by *Leverett* clay. The figure shows that it is not a wash from the hillside, as it stands away from it. Its crystallines are those of Clarendon and Indian Hollow with a larger proportion of local material. This proves that the torrent through Big Bend was not yet sufficiently lowered to scour the old Kinzua-Allegheny filling.

Middle Big Bend Gravels.—The stagnant ice was cleared from nearly the whole of the Conewango valley. There was a sculpturing of the various deposits and of the northern side of the Oakland Cemetery bar as the current was permitted to pass to the north of it. The level of the water fell and the stream through Big Bend col passed into shallower water, where the sudden broadening west of Glade checked the current. The burden of the discharge from Lake Wright changed with the lowering col, and now consisted of the filling of the old Allegheny Valley, which formed a lower and broader terrace bar hanging to the southern side of the present valley at a lower level than the one dropped in the last period,

FIG. 48.—*Middle* and *Late Big Bend* gravels, South Warren terrace-bar, Warren Co

and of entirely different materials. Figure 48 gives a working face and a fresh section. The portion beneath the conglomerated top belongs to this period: that top to the next one, and the thick clay that has been cleared from the shelf on top is the *Leverett* clay. The camera is 150 feet from the face, the height of which can be inferred from the gravel cars. The boulders are mainly from the top clay, and show iceberg action. The cobbles and boulders are far larger and more numerous than in the *Clarendon* gravels. The following divisions are shown in the figure, taken in 1897:

Middle Big Bend Gravels

A. Coarse gravel. 5 ft. No clay; little sand; wavy strata, horizontal to slight foreset dip westward. Depth unknown; pebbles up to 3 inches diameter.

B. Lenticular sandy streaks; wavy strata parallel to (A); 3 to 4 feet thick.

C. Foreset beds of assorted pebbles; dip 17°; 10 to 12 feet thick; smoothed along a horizontal plane about 20 feet above track level. UNCONFORMITY.

Late Big Bend Gravels

Unassorted gravels, sandy and carrying big boulders; 18 to 20 feet: foreset bedding; dip 17°. Top smoothed to horizontal plane.

A sample from (C) was washed and screened to 3 sizes: over one-half inch, one-fourth to one-half inch, less than one-fourth inch. Of the first, hand-picked, less than one per cent. were crystallines. There were 110 sandstones, 74 shales and 19 limestones. Of the second, there were 3.6 per cent. of crystallines—all angular pieces of black syenite. Of the third,

FIG. 49.—Clastics from South Warren terrace-bar, showing mixture of decayed and fresh pieces of same formation.

there were 20 per cent. of crystallines. This tells the story of preglacially aged crystallines comminuted in the rearrangement, as in their fresh state they are far harder and denser than the local clastics.

Preglacial decay is shown in Figures 49 and 50: the former clastics, the latter crystallines from this terrace. The large slabs in 49 are from the old surficial mantle near the outcrop, and are not only more angular and porous than the fresh rock, but their calcite fossils have been almost entirely leached away. The rolled pieces from the same formation occur next them in the formation, have been exposed to the same weathering since deposition, and are still hard, dense, and with polished calcite fossils. In 50 the cobble under the arrow was from the surficial mantle, had a decayed crust, was glaciated till the fresh white nucleus showed on one side. Similar ones have been found at Clarendon. Here also decay preceded rolling. Figure 51 shows the end of the bar cut through by the country road. The dashed line shows the form before the cutting. The capping of *Leverett* clay is seen on the farther side of the road to show that

Fig. 50.—Crystallines from South Warren terrace-bar, showing mixture of decayed and fresh pieces. Cobble under arrow has fresh (white) nucleus exposed by rolling.

Fig. 51.—Western end of South Warren terrace-bar, showing shaping before deposition of *Leverett* clay.

the sculpturing occurred before its deposition. It is sandier here than in 48, and the sand is freer from iceberg burden.

Glacial Lake Leverett.—The reason for this name is given in chapter three. In form this lake resembled Temagami in its spider-like arms, its long shore line and its small area in Pennsylvania. It is the interpreter of the Tionesta (old Middle Allegheny) glacial history.

Period One extends from its separation from the main ponding, in front of the main trunk of the ice-sheet, to its discharge over the Foxburg col. This period followed the first of Lake Wright by the interval necessary to pass from the old Allegheny to the old Tionesta mouth in Erigan Valley. The contemporary events are:

Trenching of Barnesville col to 1440.

Discharge of Upper Oil Creek drainage over Titusville col.

Deposition of clays in Lower Oil Creek Valley.

Beginning of the trenching of Thompsons col.

Drainage of lake through marginal canyon, and no glacial overwash sent up the flooded Tionesta. Overwash from Titusville, Thompsons and Barnesville.

(?) At the end of this period the lake level backed up over Barnesville, so that the upper sands at Clarendon were smoothed at 1443.

The following deposits can not be synchronized, as they are disconnected with one another, and with those of Lake Wright. The 3 feet of blued clay against the rock floor at Oil City came from the deforestation of the Upper Oil Creek basin. It is overlaid by the yellowish sandy clay cap with local enclosures. Between Petroleum Center and Plumer the lower clay is mottled and streaked, bluish-yellowish-whitish-brown, enclosing flakes of shale, pitted, abounding in shots of limonite, and the clay itself is filled with nodules of the mineral. This is denser than the sandy drift above it. At Franklin the blued clay is overlaid with red silt enclosing local gravel of red color, as shown in the trench for the water main which extends from water level to 1500 feet above ocean level—a total of 500 (vertical) feet. Above the level of the stream bed the silty wash against the rock floor is overlaid by gravelly drift, and this is found on the hill south of the town..

Period Two covers the trenching of Foxburg col from 1450 to 1300. The contemporary events are:

The trenching of Barnesville col to 1300.

The trenching of Titusville and Thompsons cols to permit the passage of gravels.

The discharge of the greater part of the glacial ablation through the marginal canyon, with a slight flow up the Tionesta from the ice-margin to bring sands to Franklin—perhaps through Sugar Creek.

The discharge of the regional drainage over Foxburg col through West Sandy Creek by reversal of drainage.

The water-laid drift at Tidioute was dropped on the slack-water side of the channel up to 1420: on the current side, to 1300. The gravel is similar to that of the bar opposite the mouth of Brokenstraw Creek. This same gravel forms the bar across the mouth of Tionesta River at its confluence with the present Allegheny. It does not exist in the stream above or on either side of Barnesville col. The gravel beds below Tionesta probably belong to this period, as a starting point, with a finish later. Here also began the filling back of Egbert Hill, and that in West Sandy Valley from Takitezy southward.

Period Three begins with the flow over Fosters col, and ends with this and Foxburg col trenched to their present rock floors. The contemporary events are:

The arrival of the ice-margin across the mouth of West Sandy Creek, and its progress to its farthest extent.

The complete closing of West Sandy Creek mouth, and the temporary stoppage of all flow through it and over Foxburg col other than that from the ablation of the ice in and to the west of West Sandy basin.

The rise of the lake level to that of the lowest col (Fosters), (1500).

The reversal of flow in East Sandy Creek Valley.

The passage of the torrent (combined flow from Barnesville, Thompsons and Titusville) at 1500 across the old divide from Egbert Hill southeastward.

The trenching of the old divide to present water level.

The completion of the filling back of Egbert Hill.

The backing up of the water at 1500 about Warren, Titusville, Clarendon, Salamanca, Olean, and Port Allegany. The development of beach-lines, terraces, swamps, etc., from 1500 to 1450.

The filling of Barnesville trench with gravel.

The deposition of *Leverett* clay as above noted.

The clearing of the main channel from stagnant ice.

The arrival of the marginal torrent seems to have been contemporaneous with that of the ice-margin as a stopper across West Sandy Valley mouth. That margin extended across Oil Creek, opening fanwise with the center of motion on the highlands of McKean County. This would bring the ice-margin and the marginal torrent across the col at Fosters. Its elevation was probably 1500, as its sheer walls rise to nearly that elevation today—the south one, against which the torrent hurled itself, being the more steep. The recency of the trenching of the old divide back of Egbert's Hill is shown in Figure 52. On the sheer walls are deposits of dense cobbly drift, with the cobbles highly polished. The trenching thus preceded the drift-sheet. The depth of flooding is shown by the height of iceberg action. In the sands we find stones from ice-cakes. One of them at 1500, on top of the hill south of Franklin in sand was a piece of red granite with quarry face and no sign of glaciation. It did not come in the ice-sheet, as it was so decayed as to be friable and even pulverulent. It is difficult to see how it escaped crushing. Near it was a fresh cobble of black gneiss similarly left. This latter rock was found at intervals nearer Franklin and at lower elevations.

Beginning at the north, we find *Leverett* clay at and above 1400 as far as Fosters: below we find it up to 1300. The Sheffield terrace, the Roystone delta and swamp are 1442-1450. The Clarendon swamp, 1400. The top of the highest terrace in Barnesville trench, 1360. Figure 53 shows

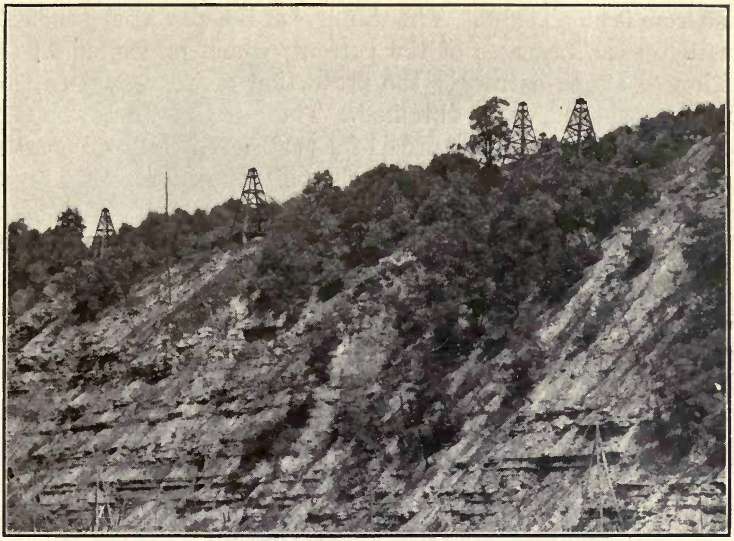

FIG. 52.—Sheer walls of trench through "Old Divide" lined and capped by drift, Franklin, Venango, Co.

FIG. 53.—*Orogenic* drift beneath *Leverett* clay, Roystone, Warren Co.

the local drift beneath clay 2 miles east of Roystone. Figure 54 shows the surface of the clay and the trash brought from Kane by ice-cakes. The cleared surface of the South Warren gravels, Figure 48, indicates at least 10 to 12 feet of *Leverett* clay. At the end of this terrace-bar (Figure 51) this clay is less than 2 feet thick. It is not a slope wash, either here or at the Oakland Cemetery, as both stand out into the plain and rise from it on all sides. The thinness of the clay at the ends of each is caused by the nearness of the current, which prevented as thick a deposition of strata as nearer the protection of the wedge-end behind which the slackened water obtained. There is thus the same thinning out of strata as shown in Figure 41 for the Indian Hollow deposits, and the same shaping of deposits at the time of deposition. The proximity to the current also prevented the lingering or accumulation of icebergs and cakes, and thus the *Leverett* clay is mainly a clean sand here, free from inclusions.

FIG. 54.—Iceberg burden in *Leverett* clay, surface at Roystone, Warren Co.

The coarse gravels at Sheffield belong to the commencement of this period, if not to the middle and end of the last. They came from Kane during the presence of the ice there, and by them Barnesville col was trenched. The other gravels of this period are found about and below Franklin, and are also of the bar type, but dropped in water whose depth was greater in proportion to the average elevation of the region above ocean level, as the Franklin crests do not rise much over 100 feet above the highest ponded water, while those about Warren rise over 500 feet above. Flooding about Franklin meant, therefore, a submergence of the lesser ridges, a short-cutting of currents entirely away from the preglacial channels, a formation of areas of slackened currents which would invite deposition indifferently over former channels, and along hillsides at all elevations. As cols were trenched and water levels fell there would be a shaping of these deposits to present forms, and a capping by washes of various origins.

Fig. 55.—Drift overlaid by assorted gravels. Brandon, Venango Co.

Fig. 56.—Thinness of *Leverett* clay over assorted gravels, Kennerdell, Venango Co.

The Brandon and Kennerdell deposits are good examples, as they are but 4 miles apart, but at different elevations. The Franklin quadrangle shows their location, the valley cross-sections, and their relation to the regional cols. The valley breadth at Brandon is six times that at Kennerdell. The current velocity is correspondingly lower. The deposits came after the clearance of the channel from stagnant ice, and with Foxburg col at 1300 above ocean level. There is gradual decrease in the sizes of the pieces from Brandon to Kennerdell, the coarse gravels and the thickest clays being at the former. They are dropped on top of the land-laid drift, which is shown at Brandon in Figure 55 beneath the gravels. The coarse gravels extend at this place to 1200 above ocean level, and 200 feet above their top at Kennerdell, where the deposit between 1000 and 1100 is composed of fine gravel and silt. At Brandon there is sand with 50 per cent. gravel between 1200 and 1300; at Kennerdell this is found between 1100 and 1200. On each is a sporadic angular wash with 1 per cent. of gravel, reaching 1400 feet at Brandon and 1300 at Kennerdell. The *Leverett* clay at Brandon varies from 8 to an average of 5 feet; at Kennerdell, 2 feet, as shown by Figure 56. There is thus no valley filled with gravel by ordinary agencies, and with subsequent erosion. The portion between Polk and Takitezy shows by its irregular surface the action of an ice-sheet.

There was no regular valley filling below Foxburg as shown by the difference in elevation of gravel on opposite sides of the river at the following places. The first figures are the instrumental elevations of gravel on the east side; the second, on the west. Foxburg, 1135-1230; Monterey, 1125-1078; East Brady, 1115-1231; Red Bank, 1100-1060. It seems that these gravels are washes carried by torrential currents with ice-cakes to such elevations as the regional contours favored. This case is like that in the Juniata Valley.

The Border of the Ice-sheet.—The land-laid drift north of Thompsons must be found above 1600 to show freedon from ponded water, stranded bergs and beach lines. It is always modified by the washings of the ridges during the ablation of the stagnant ice—a washing of greater importance than in the east, as the ridges are thinner, and the slopes steeper, so that the drift is washed into and accumulated in the valleys. The presence of crystallines was made a *sine qua non* in the determination of drift at the following places. Except at Clarendon and Foxburg, the actual edge of the Attenuated Border was not found. The best that can be said of the other places is that the ice was there, and may have gone beyond. Below Foxburg there is a general submergence and a general washing which makes the location of the Border very difficult. In so brief a reconnaissance as was permitted the writer during the few weeks of each year, only the points most easy of access were reached. The boundary has been drawn to Kane and Clarendon, with an apex south of that at Salamanca. Thence it will be drawn through the following places:

Cobham.—Three miles east of Allegheny River, at 1700, a drift-sheet of red silt including angular and rolled cobbles and some gravel, carried along ridge-crest 3 miles east of river, and also south to Tidioute.

Hickory.—Granite cobbles are reported on the ridge east of the above river.

South Oil City.—Drift beneath *Leverett* clay 1½ miles south of the river at 1460. At higher elevations to the south red granite appears in the field cullings. At 1520 red silt drift on sandstone includes sandstone pieces harder than the rock floor. The rolled pieces are less than one in one million.

Coal City.—Two miles east of Brandon at 1561 is a surface of drift similar to that about Kane, but with rounded cobbles and boulders. These last differentiate this from the gravels, which carry no boulders, see Figure 55.

Foxburg.—This is south of the col, and the average water level is 1200. On the St. Petersburg road at 1170 the scoured rock floor is capped with 2 feet of drift (silt) enclosing foreign rocks. This continues over one crest and to the top of the next at 1320, covering a coal outcrop. Below the last crest pieces of black gneiss and basalt were found, and coal flakes from the outcrop were carried up hill. The drift ends on the crest, and beyond it the rock is decaying in place.

These points are thus distant from the great moraine: Clarendon, 17 miles; Cobham, 17; Tidioute, 15; Hickory, 19; South Oil City, 14; Coal City, 10; Foxburg, 22. The boundary of the Attenuated Border is thus everywhere east of Allegheny River from Clarendon to Foxburg, with an average of 17 miles from the great moraine. This completes the parallelism between the two, and prompts the question whether these are not results of different phases of the same ice-sheet.